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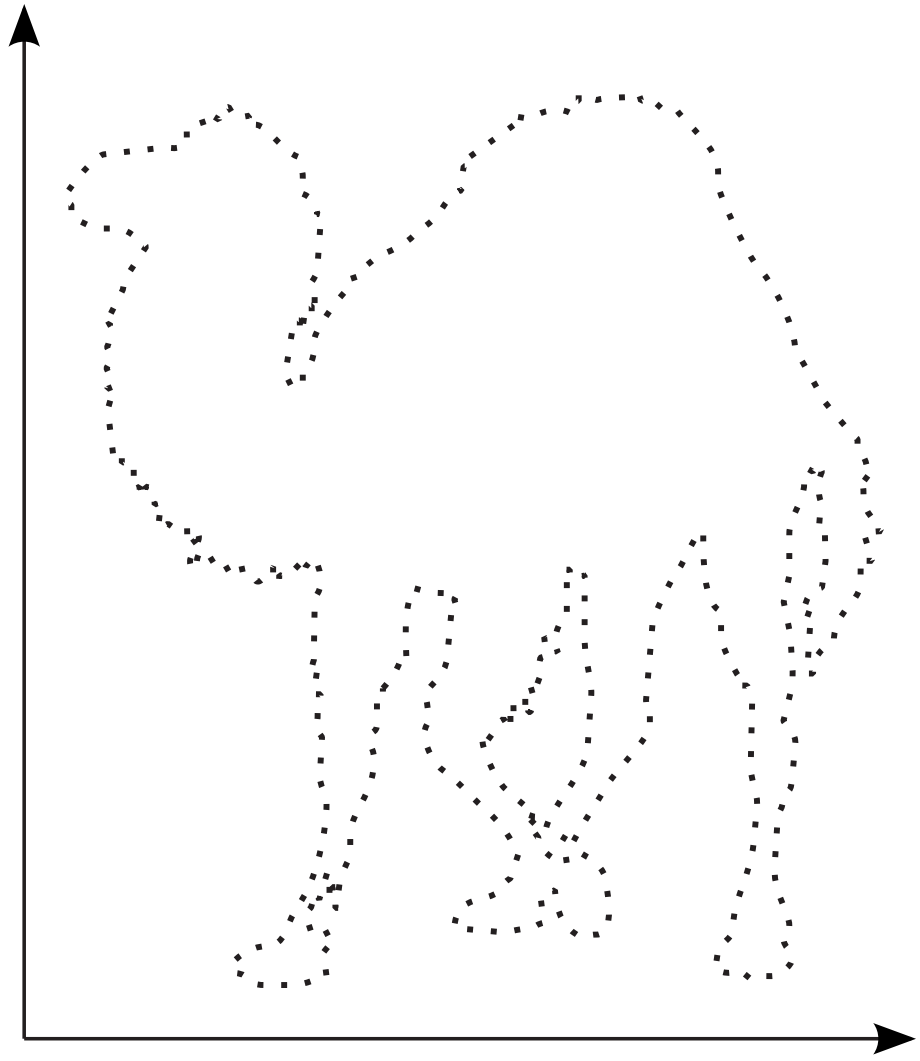
Lab::Measurement documentation



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1 The Lab::Measurement package

1.1 Lab::Measurement 3.10

Lab::Bus and Lab::Connection classes

* Initial support for the USBtmc Linux kernel driver
  * GPIB termination characters are now handled identically in LinuxGPIB and VISA_GPIB
  * New VISA_RS232 connection which takes all arguments as RS232

Lab::Instrument classes

* HP34420A nanovoltmeter re-added
  * Many improvements in the Oxford Instruments ITC503 driver
  * Re-named the Oxford Instruments IPS12010 driver to OI_IPS, since it works with not only the IPS 120-10
  * New driver: Trinamic PD-110-42 stepper motor

Lab::Measurement classes

* Started refactoring the keyboard handling code

1.2 Lab::Measurement 3.00 (initial release)

This section gives an overview of the most important points when you port a measurement script from the old (i.e., pre-2.9 or distributed under the name Lab::VISA) `Lab::Instrument` and `Lab::Tools` distribution to `Lab::Measurement`.

Lab::Instrument classes

- The abbreviated way of specifying a GPIB board and address in the constructor is not supported anymore. Instead of the old

  ```
  my $hp=new Lab::Measurement::HP34401A($board, $address);
  ```

  you now have to explicitly provide

```
my $hp=new Lab::Measurement::HP34401A({
      connection_type => 'LinuxGPIB',
      gpib_board      => $board,
      gpib_address    => $address,
});
```

- The configuration parameters "gpib_board" and "gpib_address" are now for consistency spelled all in lowercase. Your script will fail if you use the uppercase "GPIB" variant.
- Every device now needs a configuration parameter "connection_type" (see above).
- In general, functions that read out device values are all prefixed with "get_" now, instead of "read_".
- Since the Lab::Instrument::Source class has been extended to cover current and voltage sources, the parameters for influencing gate protect have been renamed. Instead of "gp_max_voltage" you now have to use "gp_max_units", and analogously for all other gateprotect parameters.
- SR830 functions like get_range and get_tc do not return strings anymore, but values in SI base units

Lab::Measurement class

- The default file suffixes have been changed from "DATA" and "META" to "dat" and "meta".
- You can not abort the scripts using Lab::Measurement with "CTRL-C" anymore. Instead, just press "q", and the script will cleanly terminate at the next measurement point. The background for this is that some device drivers cannot handle an interruption, leading to undefined hardware behaviour.

1.3 COPYRIGHT AND LICENCE

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1.4 Lab::Measurement::Installation

Installation guide for Lab::Measurement

Introduction

Since Lab::Measurement does not contain any device driver code itself, its installation is pretty straightforward. However, before you can actually use it, you will have to install a driver binding back-end, such as Lab::VISA or Linux-GPIB, plus its dependencies. Please see the documentation of these packages for more details.

Installation on Windows XP with ActiveState Perl

Install Perl.

- Tested with ActivePerl from http://www.activestate.com/Products/activeperl/index.mhtml
- Make sure to include Perl Package Manager.
- Make sure to activate the check box to include perl directory in PATH variable.

Install gnuplot (not mandatory)

- Download from http://sourceforge.net/project/showfiles.php?group_id=2055 (gp425win32.zip)
- Extract and put it somewhere
- Add directory containing `pgnuplot.exe` to path: My Computer => Properties => Advanced => Environment Variables

Install the dependencies of our perl modules. Depending on how familiar you are with the perl infrastructure, the easiest might be to use PPM, the Perl Package Manager included with ActivePerl.

Lab::Measurement needs

```
XML::Generator (PPM would write it as XML-Generator)
XML::DOM
XML::Twig
YAML
```

Install Lab::Measurement

- Unzip/copy sources
- Run the following commands in the source directory

```
perl Build.PL
perl Build
perl Build install
```

Have fun!

Installation on Windows XP with Strawberry Perl

Strawberry Perl is a Perl distribution for Windows that most closely mimics a Perl installation under Linux. It comes with gcc compiler, dmake and the other relevant tools included.

Lab::Measurement should in principle install out of the box with just the command

```
cpan Lab::Measurement
```

executed on the commandline.

Installation on Linux

As a Linux user you will probably be able to figure out most things yourself.

Install the dependencies

Best you'll use your distribution package management. You need

```
XML::Generator
XML::DOM
XML::Twig
YAML
... and GnuPlot
```

Install Lab::Measurement

- Unzip/copy sources
- Run the following commands in the source directory

```
perl Build.PL
perl Build
perl Build install
```

Have fun!

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1.5 Lab::Measurement::Tutorial

Tutorial on using the Lab::Measurement package stack

1.5.1 Introduction

The Lab::Measurement package stack allows to perform test and measurement tasks with Perl scripts. It provides an interface several hardware driver backends. Dedicated instrument driver classes relieve the user from taking care for internal details and make measurements as easy as

```
$voltage=$multimeter->get_voltage().
```

The Lab::Measurement software stack consists of several parts that are built on top of each other. This modularization allows support for a wide range of hardware on different operating systems. As hardware drivers vary in API details, each supported one is encapsulated into perl modules of types Lab::Bus and Lab::Connection. Normally you won't have to care about this; at most, your Instrument object (see below) gets different initialization parameters.

A typical measurement script is based on the high-level interface provided by the modules Lab::Instrument and Lab::Measurement. The former silently handles all the protocol overhead. You can write commands to an instrument and read the result. Drivers for specific devices are included, implementing their specific command syntax; more can easily be added to provide high-level functions. The latter includes tools for metadata handling (what was that amplifier setting in the measurement again?!), data plotting, and similar.

This tutorial will explain how to write measurement scripts. However, this tutorial does not intend to teach the Perl language itself. Some introduction into VISA and GPIB terminology is given, but then some familarity also with these concepts is assumed. If you feel the need for more information on Perl or VISA/GPIB, please see the References section [1-6].

1.5.2 Measurement automation basics

This section provides a very brief introduction to various ways of connecting measurement instruments to your control PC. We focus on the methods not so well-known to average PC users, i.e. VISA and GPIB programming. Usage of the higher level modules from the *Lab::Instrument* package requires almost no knowledge about VISA and GPIB at all, though.

VISA

Traditionally, test and measurement instruments can be connected and controlled via various standards and protocols. VISA, the Virtual Instrument Software Architecture [1,2], is an effort to provide a single standarised interface to communicate with

instruments via several protocols. It was developed by the VXIplug&play Systems Alliance[4] and is currently maintained by the IVI foundation [5]. VISA can control VXI, GPIB, serial, or computer-based instruments and makes the appropriate driver calls depending on the type of instrument used. Hence, VISA is located in the application layer. The National Instruments NI-VISA library is one implementation of the VISA standard.

In one word: VISA tries to make it unimportant, how an instrument is connected physically.

GPIB

GPIB (IEEE488)[3] is a lower lying standard invented by Hewlett-Packard. It describes a way of connecting instruments. The standard is divided into the physical layer IEEE488.1 that defines cables and signals and the command layer IEEE488.2 that describes a syntax for messages between communicating instruments. SCPI (Standard Commands for Programmable Instruments) is an extension of IEEE488.2 and refines the available commands further, with the goal of obtaining a language that is independent of the exact model of the instruments in use. This could be very useful, as, in theory, it would allow you to exchange one instrument in your setup with a similar one from another manufacturer, without having to change your measurement software. In practise however, not many instruments support this standard, and even if, small differences make things a pain. As described below, the Lab::Instrument package follows another route to achieve interchangeability by providing common interfaces for similar instruments at a much higher level (e.g. the *Lab::Instrument::Source* interface).

In one word: GPIB tries to make communication with various instruments more similar.

RS232

RS232 is the abbreviation for the serial port that used to be built into each PC. It provides a point-to-point connection to one instrument.

1.5.3 Architecture

A schematic view of the various software layers between your perl measurement script and the instrument hardware is depicted in the graphics http://www.labmeasurement.de/structure.png.

The lowermost layer is provided by the hardware driver library and its Perl binding. One option for this is under Linux the package LinuxGPIB, which comes wth its own Perl bindings module. Alternatively, National Instruments NI-VISA can be used. In that case, the module *Lab::VISA* is required to access the library functions from Perl; it makes the standard VISA calls available from within Perl programs. This layer is not part of the Lab::Measurement distribution, but must be installed separately.

Each hardware backend is encapsulated into a class of the *Lab::Bus* type. A Bus can be imagined as a cable, connecting your control computer with several measurement hardware components. On top of the Bus classes, classes of type *Lab::Connection*

operate. Each connection, well, connects one measurement instrument with your script. Usually, the handling of Bus and Connection is transparent; as long as you dont want to add more backends or enhance the functionality, you will never have any need to directly address these levels.

The *Lab::Instrument* classes build on top and simplify the routine tasks of opening a connection to an instrument, sending and receiving messages. This is the level where usually customized measurement scripts access the protocol stack. Classes derived from *Lab::Instrument* as e.g. *Lab::Instrument::KnickS252* are specialized modules for certain instruments. Most other measurement software packages would call this a virtual instruments or an instrument drivers. Each such class provides methods that are specific for one instrument. The Lab::Instrument::IPS120_10 class for example class is dedicated to a certain magnet power supply and therefore provides methods like `set_target_field`. Similar instruments (e.g. various voltage sources) can share common interfaces (e.g. *Lab::Instrument::Source*) to make interchangeability of similar instruments possible.

The highest abstraction layer is provided by the *Lab::Measurement* class, which contains methods for data and metadata handling, plotting and rudimentary keyboard control.

1.5.4 Using the Lab::Instrument class

The *Lab::Instrument* class can do for us the routine work of connecting to an instrument.

```
#!/usr/bin/perl

use strict;
use Lab::Instrument;

##################################

unless (@ARGV > 0) {
      print "Usage: $0 GPIB-address\n";
      exit;
}

my $gpib=$ARGV[0];

print "Querying ID of instrument at GPIB address $gpib\n";

my $i=new Lab::Instrument(
      connection_type=>'LinuxGPIB',
      gpib_address => $gpib,
      gpib_board=>0,
);

my $id=$i->query('*IDN?');
```

```
print "Query result: \"$id\"\n";
```

This program opens a GPIB instrument for communication, sends the command *IDN? and reads out its response, the identification string of the instrument. All handling of GPIB boards, resource managers etc. is done within the Lab::Instrument class; we don't have to care about string lengths and cleaning up. Lab::Instrument does it for us. Now that's already quite nice, eh?

By only using *Lab::Instrument* you should already be able to do about everything that can be done with the instruments in your lab.

1.5.5 Using Lab::Instrument::xxx virtual instruments

Many common tasks, like reading a voltage from a digital multimeter, require that a series of GPIB commands is sent to an instrument. These commands are different for similar instruments from different manufacturers.

The virtual instrument classes in the *Lab::Instrument* package attempt to hide these details from the user by providing high level methods like `set_voltage($voltage)` and `get_voltage()`.

Additionally they provide an optional safety mechanism for voltage sources. This is used to protect sensitive samples which could be destoyed by sudden voltage changes. See the documentation of the *Lab::Instrument::Source* module for details.

```
#!/usr/bin/perl

use strict;
use Lab::Instrument::HP34401A;

##################################

unless (@ARGV > 0) {
      print "Usage: $0 GPIB-address\n";
      exit;
}

my $hp_gpib=$ARGV[0];

print "Reading voltage from HP34401A at GPIB address $hp_gpib\n";

my $hp=new Lab::Instrument::HP34401A(
      connection_type=>'LinuxGPIB',
      gpib_address => $hp_gpib,
      gpib_board=>0,
);

my $volt=$hp->$get_voltage_dc(10,0.00001);

print "Result: $volt V\n";
```

This example show the usage of a dedicated virtual instrument class, namely *Lab::Instrument::HP34401A*, the driver for a Hewlett-Packard/Agilent 34401A digital multimeter. An instance of this class is created that is connected to one certain instrument. We use the `get_voltage_dc()` method that configures the multimeter for dc voltage measurement in the range given by the parameters, triggers one measurement, and returns the measured voltage value.

Next we show an example on how to use the safety mechanism of *Lab::Instrument::Source* that is inherited by voltage sources like *Lab::Instrument::Yokogawa7651*.

```
#!/usr/bin/perl

use strict;
use Lab::Instrument::Yokogawa7651;

unless (@ARGV > 0) {
      print "Usage: $0 GPIB-address [Target-voltage]\n";
      exit;
}

my ($gpib,$goto)=@ARGV;

my $source=new Lab::Instrument::Yokogawa7651(
      connection_type=>'LinuxGPIB',
      gpib_address => $gpib,
      gpib_board=>0,
      gate_protect=>1,
      gp_max_unit_per_second=>0.05,
      gp_max_unit_per_step=>0.005
      gp_max_step_per_second=>10,
);

if (defined $goto) {
      $source->set_voltage($goto);
} else {
      print $source->get_voltage();
}
```

Here the gate_protect mechanism limits the step size of the voltage source to 0.005mV, and the sweep speed to at most 10 such steps per second. This is implemented automatically within the `set_voltage($goto)` command; after we have set the parameters in the initialization phase, we do not have to take care of it anymore.

1.5.6 Using the high-level Lab::Measurement and related classes

With the tools introduced so far you should be able to easily write short individual scripts for your measurement tasks. These scripts will probably serve as well as all other home grown solutions using LabView or whatever. The `Lab::Measurement` class together with the related `Lab::Data:...` classes now provide additional tools to write better measurement scripts.

One main goal is to provide means to keep additional information stored along with the raw measured data. Additional information means all the notes that you would usually write down in your laboratory book, like date and time, settings of additional instruments, the environment temperature, the color of the shirt you were wearing while recording the data and everything else that might be of importance for a later interpretation of the data. In my experience, having to write these things in a book by hand is tedious and error-prone. It's the kind of job that computers were made for.

Another goal is to free the experimenter from having to repeat himself all the time when the data is used for analysis or presentation. Let us assume that, for example, you are measuring a very small current with the help of a current amplifier. This current amplifier will output a voltage that is proportional to the original current, so in fact you will be measuring a voltage that can be converted to the original current by multiplying it with a certain factor. But as long as the precise formula for this transformation is not stored together with the data, you will still find yourself repeatedly typing in the same expressions, whenever you work with the data. This is where the *axis* concept comes into play. Already at the time you are preparing your measurement script, you define an *axis* named *current* that stores the expression to calculate the current from the voltage. From there you work with the current-axis and will never have to care about the conversion again. And of course you can define many different axes. Read on!

The metadata

The general concept is that a *dataset* is composed out of *data* and *metadata*, i.e. additional information about the *data*. This *metadata* is maintained by the *Lab::Data::Meta* class and is usually stored in a file `dataset_filename.meta`, while the *data* is saved in `dataset_filename.dat`.

The *meta* file is stored in YAML or XML format and contains a number of elements which are defined in *Lab::Data::Meta*. The most important ones are *column*, *block*, *axis* and *plot*. For the following discussion of these fields, let's assume a *data* file that looks like this:

```
0.01    2.0    3
0.01    2.1    3.4
0.01    2.2    2.9

0.02    2.0    1.7
0.02    2.1    2.4
0.02    2.2    2.2
```

This dataset shows an example where one quantity (third column) is measured in dependence of two others (first and second column). The data was recorded in two traces, where one input value is kept constant (1st column) and then for every setting of the other input value (2nd column) a datapoint is taken (3rd column). Then the the first input value is increased and the next trace is recorded.

column The above example measurement has three columns. You will want to store additional information for each of these columns: What is being set or measured, what is the unit of the stored value etc. This information is stored in the *column* records of the *meta* file. More details on the available fields is given in the *Lab::Data::Meta* manpage.

block The example data above was aquired in two traces or scans or sweeps, which are separated by an empty line in the *data* file now. *Lab::Data::Meta* adopts the Gnuplot[7] terminology and calls these *blocks*. Along with every block, additional information like the time the trace was started can be saved. Most of this is done automatically. See the *Lab::Data::Meta* and *Lab::Measurement* manpages.

axis Usually you will not want to work with the raw data as it is stored in the columns of the file. For example you could want to plot the sum of two columns. Also you might want to display the data using another unit. Therefor you can define a new axis, that is defined as the sum of these two columns times any factor (which can be saved as a constant, see below) for the right unit. The expression `amp * ($C1 + 10 * $C2)` defines an axis as the sum of two columns multiplied with a constant `amp`. Additionally, axes have labels, ranges and such.

plot With the plot element, default views on the data be defined. These views can then be plotted with a single command, using the *Lab::Data::Plotter* module and the script `plotter.pl`. Because all the necessary information is stored in the *meta* file, these plots will automatically contain the right axes, ranges, labels, units and any other information you wish! Plots can already be defined at the time the measurement script is written, and can also be added later. If you use the *Lab::Measurement* module, you can display any of these plots live, while the data is being aquired. Since this entire system can run on Linux, you can X-forward this graph to your remote desktop at the beach. Imagine the possibilities.

constant This section of meta data can be used to store additional values that are important for the later interpretation of the raw data. Examples for such values could be amplification factors, voltage dividers etc. Constants have names that can be used in expressions of `axis` definitions.

The Lab::Measurement class

The *Lab::Measurement* class makes it easy to write a measurement script that takes advantage of the meta data system introduced above...

Examples

```
use strict;
use Lab::Instrument::Yokogawa7651;
use Lab::Instrument::IPS12010;
use Lab::Instrument::HP34401A;
use Lab::Instrument::SR830;
use Lab::Measurement;

# measurement range and resolution
my $Vbiasstart = -0.0036;      # V, after divider
my $Vbiasstop = 0.0036;        # V, after divider
my $Vbiasstep = 0.00002;       # V, after divider
my $Bstart=0.1;                # T
my $Bstop=0;                   # T
my $Bstep=0.01;                # T

# general measurement settings and constants
my $Vbiasdivider = 0.01;       # <1, voltage divider value
my $currentamp = 1e-9;         # A/V
my $sample = "nanotube";
my @starttime = localtime(time);
my $startstring=sprintf("%04u-%02u-%02u_%02u-%02u-%02u",
              $starttime[5]+1900, $starttime[4]+1, $starttime[3],
                      $starttime[2], $starttime[1], $starttime[0]);
my $title = "Bias␣versus␣magnetic␣field";
my $filename = $startstring."_biasfield";

# the bias voltage source
my $YokBias=new Lab::Instrument::Yokogawa7651({
       'connection_type'=> 'LinuxGPIB',
       'gpib_board'     => 0,    'gpib_address'  => 3,
       'gate_protect'   => $Vbiasprotect,
       'gp_max_unit_per_second' => 0.05/$Vbiasdivider,
       'gp_max_step_per_second' => 10,
       'gp_max_unit_per_step' => 0.005/$Vbiasdivider,
       'fast_set' => 1,
});

# the lock-in: ac measurement
my $SRS = new Lab::Instrument::SR830({
       'connection_type'=> 'LinuxGPIB',
       'gpib_board'     => 0,    'gpib_address'  => 8,
});

# the multimeter: dc measurement
my $HP = new Lab::Instrument::HP34401A({
       'connection_type'=> 'LinuxGPIB',
       'gpib_board'     => 0,    'gpib_address'  => 12,
});

# the superconducting magnet control
my $magnet=new Lab::Instrument::IPS12010({
       'connection_type' => 'LinuxGPIB',
       'gpib_board'     => 0,    'gpib_address'  => 24,
});
```

```
# general comments for the log
my $comment=<<COMMENT;
Bias sweeps versus magnetic field; gate voltage -3.74 V
B from $Bstart to $Bstop step size $Bstep
Bias voltage from $Vbiasstart to $Vbiasstop step size $Vbiasstep
Current preamp $currentamp A/V
SRS lock-in: integrate 100ms, freq 117.25Hz, sensit. 10mV
COMMENT

# the "measurement": things like filename, live plot, etc,
# plus all the metadata (data file columns, axes, plots, ...)
my $measurement=new Lab::Measurement(
sample          => $sample,         title           => $title,
filename_base   => $filename,       description     => $comment,
live_plot       => 'currentacx',    live_refresh    => '200',
constants       => [
      {   'name'          => 'currentamp',
      'value'         => $currentamp,
      },
],
columns         => [ # documentation of the data file columns
      {   'unit'          => 'T',   'label'         => 'B',
      'description'   => 'magnetic field perpendicular to nanotube',
      },
      {   'unit'          => 'V',   'label'         => 'Vbias',
      'description'   => "dc bias voltage",
      },
      {   'unit'          => 'A',   'label'         => 'Idc',
      'description'   => "measured dc current",
      },
      {   'unit'          => 'A',   'label'         => 'Iac,x',
      'description'   => "measured ac current, x component",
      },
      {   'unit'          => 'A',   'label'         => 'Iac,y',
      'description'   => "measured ac current, y component",
      },
],
axes            => [ # possible axes for plotting, and their data
    columns
      {   'unit'          => 'T',   'label'         => 'B',
      'expression'    => '$C0',
      'description'   => 'magnetic field perpendicular to nanotube',
      },
      {   'unit'          => 'V',   'label'         => 'Vbias',
      'expression'    => '$C1',
      'description'   => 'dc bias voltage',
      },
      {   'unit'          => 'A',   'label'         => 'Idc',
      'expression'    => '$C2',
      'description'   => 'measured dc current',
      },
      {   'unit'          => 'I',   'label'         => 'Iac,x',
      'expression'    => '$C3',
      'description'   => 'measured ac current, x component',
```

```
        },
        {   'unit'          => 'I',    'label'         => 'lac,y',
        'expression'    => '$C4',
        'description'   => 'measured␣ac␣current,␣y␣component',
        },
],
plots           => { # plots that can be made using the axes above
        'currentdc'     => {
        'type'          => 'pm3d',
        'xaxis'         => 0,    'yaxis'         => 1,
        'cbaxis'        => 2,    'grid'          => 'xtics␣ytics',
        },
        'currentacx'    => {
        'type'          => 'pm3d',
        'xaxis'         => 0,    'yaxis'         => 1,
        'cbaxis'        => 3,    'grid'          => 'xtics␣ytics',
        },
},
);

# correct the sign of the step sizes if required
unless (($Bstop-$Bstart)/$Bstep > 0) { $Bstep = -$Bstep; }
unless (($Vbiasstop-$Vbiasstart)/$Vbiasstep > 0) { $Vbiasstep=-
    $Vbiasstep; }
my $Bstepsign=$Bstep/abs($Bstep);
my $Vbiasstepsign=$Vbiasstep/abs($Vbiasstep);

## ENOUGH PREPARATION, NOW THE MEASUREMENT STARTS :)

# go to start field
print "Ramping␣magnet␣to␣starting␣field...␣";
$magnet->set_field($Bstart);
print "␣done!\n";

# here you could eg. check the temperature

# the outer measurement loop: magnetic field
for (my $B=$Bstart; $Bstepsign*$B <= $Bstepsign*$Bstop; $B+=$Bstep)
    {

        $measurement->start_block();

        # set the field
        $magnet->set_field($B);

        # the inner measurement loop: bias voltage
        for (my $Vbias=$Vbiasstart;
                $Vbiasstepsign*$Vbias<=$Vbiasstepsign*$Vbiasstop;
                $Vbias+=$Vbiasstep) {

        # set the bias voltage
        $YokBias->set_voltage($Vbias/$Vbiasdivider);
```

```
        # read dc signal from multimeter
        my $Vdc = $HP->get_value();

        # read the ac signal from the lock-in
        my ($Vacx,$Vacy)=$SRS->get_xy();

        # we multiply with (-1)*$currentamp (inverting amplifier)
        my $Idc = -$Vdc*$currentamp;
        my $Iacx=-$Vacx*$currentamp;
        my $Iacy=-$Vacy*$currentamp;

        # write the values into the data file
        $measurement->log_line($B, $Vbias, $Idc, $Iacx, $Iacy);
        }
};

        # all done
        $measurement->finish_measurement();
        print "End of Measurement!\n";
```

1.5.7 References

[1] NI-VISA User Manual (http://www.ni.com/pdf/manuals/370423a.pdf)

[2] NI-VISA Programmer Manual (http://www.ni.com/pdf/manuals/370132c.pdf)

[3] NI 488.2 User Manual (http://www.ni.com/pdf/manuals/370428c.pdf)

[4] http://www.vxipnp.org/

[5] http://www.ivifoundation.org/

[6] http://perldoc.perl.org/

[7] http://www.gnuplot.info/

1.6 Implementing a current/voltage source driver

This document is ment as a guideline to and a help with the implementation of drivers for current and voltage sources. Since the complexity of the `Lab::Instrument` and `Lab::Instrument::Source` classes increases, it becomes more and more cumbersome to carefully read the (sometimes outdated) class documentation to keep track of correct interfaces, i.e., required methods and return values, to provide source device drivers.

The config hash

Let us start with what comes first, the config hash. It is used to provide default values for parameters that control the higher level functionality, namely `gate_protect` and to define the device parameters that should be stored internally (e.g. the range or the current output mode). At the moment when this documentation is written, an example for a correct config hash can be found in the class definition of the YokogawaGS200:

```
our %fields = (
      supported_connections => [ 'VISA_GPIB', 'GPIB', 'VISA', 'DEBUG'
          ],

      # default settings for the supported connections
      connection_settings => {
              gpib_board => 0,
              gpib_address => 22,
      },

      device_settings => {

              gate_protect            => 1,
              gp_equal_level          => 1e-5,
              gp_max_units_per_second  => 0.05,
              gp_max_units_per_step    => 0.005,
              gp_max_step_per_second  => 10,

              stepsize                => 0.01,  # default stepsize for
                   sweep without gate protect

              max_sweep_time=>3600,
              min_sweep_time=>0.1,
      },

      # If class does not provide set_$var for those, AUTOLOAD will
          take care.
      device_cache => {
              function                        => "VOLT", # 'VOLT' -
                  voltage, 'CURR' - current
              range                   => undef,
              level                   => undef,
              output                                  => undef,
      },
```

```
        device_cache_order => ['function','range'],
);
```

Let me introduce the objects in this hash. `connection_settings` is more or less self-explanatory and should be overwritten by the user anyway.

The device_settings hash

The `device_settings` hash contains, in the case of a source driver, all the settings that are important to use the gate_protect feature of the `Lab::Instrument::Source` class. The values given are a careful choice, the user who wants to use gate protect will redefine them anyway. For a new driver, the hash can just be copy/pasted.

The `device_cache` hash

The `device_cache` hash contains all device parameters, i.e., parameters that can be set and read to and from the device, which should be stored on the software side. It is your decision what variables you add to the list, but make sure you

1. implement getter and setter for all these variables except the Current/Voltage level.
2. use `undef` as default if it is likely that this parameter is given on init. If it is not given, it will be read from the device.

The `device_cache_order` array

If the order of initializing parameters on the device is important, you should specify the order in this array.

The getter methods

The default for the getter should be to return the cached variable, i.e. the variable which is stored on the computer. If the option

```
from_device => 1
```

is given, the variable should be read from the device.

The setter methods

should always set both on device and in the software cache. You can also use a

```
error_check=>1
```

in the `$self->write>` command, then a possible error which appears on the device will automatically be set. Read also the section on error checking.

Default values

Best is to use `undef`.

Methods that MUST be provided by the device class

Please make sure you implement the following:

1. **get/set** for each variable in the device_cache with one exception: `set_level`. The setter should return the set value.

2. The sub `_set_level($target)` which will be called from `Lab::Instrument::Source` to use gate protect. Implement instead of `set_level()`.

3. A function `get_status()`.

The status sub

The sub `get_status` should read out the status byte of the device and create a hash with a descriptive flag and the state of the corresponding bit. The error bit should have the key **"ERROR"**.

Methods that should be implemented

It is convenient to implement the follwoing functions if possible:

1. A sub `_sweep_to_level($target,$time)`.

2. A sub `get_error()`.

The sweep function

`_sweep_to_level($target,$time)` is given a target level `$target` and a sweep time `$time`. If the device supports this functionality, it should be implemented here. It should return `$target`.

`get_error()`

should read out the device's error stack. It should return ONE error at once in a single array with

```
[$errorcode,$errormessage]
```

The error checking framework

It is possible to wrap every `write($cmd)` call by an error checking routine. This can be invoked by providing the option `error_check`. For example:

```
$self->write($cmd,'error_check' => 1)
```

After sending the command in `$cmd` to the device, the framework will use `get_status()` to read out the **ERROR** status bit. If it is set, `get_error()` will be used to fetch the error from the device.

General remarks on device driver developement

Allow pass-through of commands in set & get

The advanced user should be given the possibility to do dirty workarounds when using the driver. To do this, he can provide options in the `write()` call, that are interpreted on connection level. This should in general also be possible when using `set_level` or any command that involves a `write()` call.

1.7 Example scripts

1.7.1 yoko-goto.pl

Sweeps a Yokogawa 7651 dc voltage source to a value given on the command line.

Usage example

```
$ perl yoko_goto.pl 12 0.8
```

Sweeeps the Yokogawa 7651 dc voltage source with GPIB address 12 (on GPIB adaptor 0) to 0.8V, using a maximum step size of 5mV and at most 10 steps per second.

Author / Copyright

```
(c) Andreas K. H ttel 2011
```

1.7.2 query_id.pl

Queries and prints the instrumet ID of a GPIB instrument; the GPIB address is the only command line parameter.

Usage example

```
$ perl query_id.pl 3
```

Author / Copyright

```
(c) Andreas K. H ttel 2011
```

1.7.3 query_id.pl

Queries and prints the instrumet ID of an IsoBus instrument; the IsoBus address is the only command line parameter.

You will have to adapt this script first to use the correct IsoBus base connection. This base connection describes how the IsoBus is connected to your measurement PC.

For example, the IsoBus could be connected to a bus master device (often an IPS magnet power supply), and that in turn has a GPIB address. Then, the base connection would be the GPIB connection to the bus master device.

Alternatively, as shown above, the IsoBus is connected directly to the PC, and the base connection is then just the serial port.

Usage example

```
$ perl isobus_query_id.pl 3
```

Author / Copyright

```
(c) Andreas K. H ttel 2011,2013
```

1.7.4 srs_read.pl

Reads out reference amplitude, reference frequency, and current r and phi values of a Stanford Research SR830 lock-in amplifier. The only command line parameter is the GPIB address.

Usage example

```
$ perl srs_read.pl 8
```

Author / Copyright

```
(c) Andreas K. H ttel 2011
```

1.7.5 gatesweep.pl

Script to record a trace I(Vg), i.e. dc current as function of gate voltage, in a Coulomb blockade measurement.

Measurement setup

Script: configuration section

Script: metadata section

Script: actual measurement loop

Author / Copyright

```
(c) Daniel Schmid, Markus Gaass, David Kalok, Andreas K. H ttel 2011
```

1.7.6 biasfield.pl

Script to record Idc(B,Vbias) and the lock-in output Iac(B,Vbias) in a Coulomb blockade measurement.

Author / Copyright

```
(c) Daniel Schmid, Markus Gaass, David Kalok, Andreas K. H ttel 2011
    Andreas K. H ttel 2012
```

1.8 Utility scripts

1.8.1 plotter.pl

Plot data with GnuPlot

SYNOPSIS

plotter.pl [OPTIONS] METAFILE

DESCRIPTION

This is a commandline tool to plot data that has been recorded using the Lab::Measurement module.

OPTIONS AND ARGUMENTS

The file `METAFILE` contains the meta information for the data that is to be plotted. The name OR number of the plot that you want to draw must be supplied with the `--plot` option, unless you use the `--list_plots` option, that lists all available plots defined in the `METAFILE`.

--help|-?

Print short usage information.

--man

Show manpage.

--listplots

List available plots defined in `METAFILE`.

--plot=name --plot=number

Show the plot with name `name` or number `number`. Numbers are given by the `--list_plots` option.

--dump=filename

Do not plot now, but dump a gnuplot file `filename` instead.

--eps=filename

Don't plot on screen, but create eps file `filename`.

--fulllabels

Also show axis descriptions in plot.

1.8.2 metainfo.pl

Show info from meta file.

SYNOPSIS

metainfo.pl [OPTIONS] METAFILE

DESCRIPTION

This is a commandline tool to...

OPTIONS AND ARGUMENTS

The file `METAFILE` contains meta information about one dataset. This information is printed.

1.8.3 make_filelist.pl

Generate a list of all plots defined in all metafiles of the current directory

SYNOPSIS

```
huettel@pc55508 ~ $ make_filelist.pl
```

DESCRIPTION

This is a commandline tool to quickly generate a list of all plots defined in the current directory. It generates a file `filelist.txt` suitable as input of `make_overview.pl`.

1.8.4 make_overview.pl

Generate a LaTeX overview file with plots of all measurements in a directory

SYNOPSIS

```
huettel@pc55508 ~ $ make_overview.pl
```

Evaluates `filelist.txt` in the current directory, reads the specified metafiles, generates the specified plots and a LaTeX file `overview.tex`.

SYNTAX of filelist.txt

```
% Chapter 1 title
%% Section 1.1 title
Plotname        MYMEASUREMENT.META
Plotname        MYMEASUREMENT2.META
% Chapter 2 title
Plotname        ANOTHERMEASUREMENT.META
```

Pretty simple, huh? The only important thing is - the separator between the plot name and the file name has to be a TAB.

1.9 High-level tool classes

1.9.1 Lab::Measurement

Log, describe and plot data on the fly

SYNOPSIS

```
use Lab::Measurement;

my $measurement=new Lab::Measurement(
    sample              => $sample,
    title               => $title,
    filename_base       => 'qpc_pinch_off',
    description         => $comment,

    live_plot           => 'QPC current',

    columns             => [
        {
            'unit'              => 'V',
            'label'             => 'Gate voltage',
            'description'       => 'Applied to gates via low path filter
                .',
        },
        {
            'unit'              => 'V',
            'label'             => 'Amplifier output',
            'description'       => "Voltage output by current amplifier
                set to $amp.",
        }
    ],
    axes                => [
        {
            'unit'              => 'V',
            'expression'        => '$C0',
            'label'             => 'Gate voltage',
            'min'               => ($start_voltage < $end_voltage) ?
                $start_voltage : $end_voltage,
            'max'               => ($start_voltage < $end_voltage) ?
                $end_voltage : $start_voltage,
            'description'       => 'Applied to gates via low path filter
                .',
        },
        {
            'unit'              => 'A',
            'expression'        => "abs(\$C1)*$amp",
            'label'             => 'QPC current',
            'description'       => 'Current through QPC',
        },
        {
            'unit'              => '2e^2/h',
            'expression'        => "(\$A1/$v_sd)/$g0)",
```

```
            'label'             => "Total conductance",
        },
        {
            'unit'              => '2e^2/h',
            'expression'        => "(1/(1/abs(\$C1)-1/$U_Kontakt)) * (
               $amp/($v_sd*$g0))",
            'label'             => "QPC conductance",
            'min'               => -0.1,
            'max'               => 5
        },


    ],
    plots               => {
        'QPC current'     => {
            'type'              => 'line',
            'xaxis'             => 0,
            'yaxis'             => 1,
            'grid'              => 'xtics ytics',
        },
        'QPC conductance'=> {
            'type'              => 'line',
            'xaxis'             => 0,
            'yaxis'             => 3,
            'grid'              => 'ytics',
        }
    },
);


$measurement->start_block();


my $stepsign=$step/abs($step);
for (my $volt=$start_voltage;$stepsign*$volt<=$stepsign*$end_voltage;
    $volt+=$step) {
    $knick->set_voltage($volt);
    usleep(500000);
    my $meas=$hp->read_voltage_dc(10,0.0001);
    $measurement->log_line($volt,$meas);
}


my $meta=$measurement->finish_measurement();
```

DESCRIPTION

This module simplifies the task of running a measurement, writing the data to disk and keeping track of necessary meta information that usually later you don't find in your lab book anymore.

If your measurements don't come out nice, it's not because you were using the wrong software.

CONSTRUCTORS

new

```
$measurement=new Lab::Measurement(%config);
```

where %config can contain

```
sample        => '',  # see Meta
title         => '',  # single line
filename      => '',
filename_base => '',  # for auto_naming
description   => '',  # multi line

columns       => [],
axes          => [],
plots         => [],  # See Meta

live_plot     => '',  # Name of plot that is to be plotted live
live_refresh  => '',
live_latest   => '',

writer_config => {},  # Configuration options for Lab::Data::Writer
```

METHODS

start_block

```
$block_num=$measurement->start_block($label);
```

log_line

```
$measurement->log_line(@data);
```

finish_measurement

```
$meta=$measurement->finish_measurement();
```

now_string

```
$now=$measurement->now_string();
```

log($datum,$column,$description) magic log. deprecated.

1.9.2 Lab::Data::Writer

Write data to disk

SYNOPSIS

```
use Lab::Data::Writer;

my $writer=new Lab::Data::Writer($filename,$config);

$writer->log_comment("This␣is␣my␣test␣log");

my $num=$writer->log_start_block();
$writer->log_line(1,2,3);
```

DESCRIPTION

This module can be used to log data to a file, comfortably.

CONSTRUCTOR

new

```
$writer=new Lab::Data::Writer($filename,$config);
```

See *configure* below for available configuration options.

METHODS

configure

```
$writer->configure(\%config);
```

Available options and default values are

```
output_data_ext     => "dat",
output_meta_ext     => "meta",

output_col_sep      => "\t",
output_line_sep     => "\n",
output_block_sep    => "\n",
output_comment_char => "#␣",
```

Example usage is like this:

```
$writer->configure({
    output_col_sep      => ":",
    output_comment_char => "//␣",
});
```

get_filename

```
($filename,$filepath)=$writer->get_filename()
```

log_comment

```
$writer->log_comment($comment);
```

Writes a comment to the file.

log_line

```
$writer->log_line(@data);
```

Writes a line of data to the file.

log_start_block

```
$num=$writer->log_start_block();
```

Starts a new data block.

import_gpplus(%opts) Imports GPplus TSK-files. Valid parameters are

```
filename => 'path/to/one/of/the/tsk-files',
newname  => 'path/to/new/directory/newname',
archive  => '[copy|move]'
```

The path `path/to/new/directory/` must exist, while `newname` shall not exist there.

1.9.3 Lab::Data::Meta

Meta data for datasets

SYNOPSIS

```
use Lab::Data::Meta;

my $meta2=new Lab::Data::Meta({
    dataset_title  => "testtest",
    column         => [
        {label  =>'hallo'},
        {label  =>'selber hallo',
         unit   =>'mV'},
    ],
    axis           => [
        {
            unit        => 's',
            description => 'the time',
        },
        {
            unit        => 'eV',
            description => 'kinetic energy',
        },
    ],
});
```

DESCRIPTION

This module maintains meta information on a dataset. It's build on top of Lab::Data::XMLtree.

CONSTRUCTOR

new

```
$meta=new Lab::Data::Meta(\%metainfo);
```

Currently, `Lab::Data::Meta` supports the following bits of meta information:

```
data_complete               => ['SCALAR'],  # boolean

dataset_title               => ['SCALAR'],
dataset_description         => ['SCALAR'],  # multiline
sample                      => ['SCALAR'],
data_file                   => ['SCALAR'],  # relativ zur
    descriptiondatei

block                   => [
    'ARRAY',
    'id',
    {
```

```
            original_filename    => ['SCALAR'],  # nur von GPplus-Import
                unterst tzt
            timestamp            => ['SCALAR'],  # Format %Y/%m/%d-%H:%M
                :%S
            description          => ['SCALAR'],
            label                => ['SCALAR'],
        }
    ],
    column                   => [
        'ARRAY',
        'id',
        {
            unit                 => ['SCALAR'],
            label                => ['SCALAR'],  # evtl. weg
            description          => ['SCALAR'],  # evtl. weg
            min                  => ['SCALAR'],  # unn tz, aber von
                GPplus-Import unterst tzt
            max                  => ['SCALAR'],  # dito
        }
    ],
    axis                     => [
        'ARRAY',
        'id',
        {
            label                => ['SCALAR'],
            unit                 => ['SCALAR'],
            expression           => ['SCALAR'],
            min                  => ['SCALAR'],
            max                  => ['SCALAR'],
            description          => ['SCALAR'],  # evtl. weg
        }
    ],
    plot                     => [
        'HASH',
        'name',
        {
            type                 => ['SCALAR'],  # line, pm3d
            xaxis                => ['SCALAR'],
            xformat              => ['SCALAR'],
            yaxis                => ['SCALAR'],
            yformat              => ['SCALAR'],
            zaxis                => ['SCALAR'],
            zformat              => ['SCALAR'],
            cbaxis               => ['SCALAR'],
            cbformat             => ['SCALAR'],
            logscale             => ['SCALAR'],  # z.b: 'x' oder 'yzxcb'
            time                 => ['SCALAR'],  # ??? (was: wie oben (
                anders als in GnuPlot) (Achsen m ssen %s-Format haben))
            grid                 => ['SCALAR'],  # z.B. 'ytics' oder '
                xtics ytics'
            palette              => ['SCALAR'],
            label                => [
                'ARRAY',
                'id',
```

```
            {
                text        => ['SCALAR'],
                x           => ['SCALAR'],
                y           => ['SCALAR'],
            }
        ],
    }
],
constant                => [
    'ARRAY',
    'id',
    {
        name                => ['SCALAR'],
        value               => ['SCALAR'],
    }
],
```

new_from_file

```
$meta=new_from_file Lab::Data::Meta($filename);
```

METHODS

save

```
$meta->save($filename);
```

get_abs_path

```
my $path=get_abs_path();
```

1.9.4 Lab::Data::XMLtree

Handle and store XML and perl data structures with precise declaration.

SYNOPSIS

```
use Lab::Data::XMLtree;

my $data_declaration = {
    info                        => [#               type B
        'SCALAR',
        {
            basename    => ['PSCALAR'],#            type A
            title       => ['SCALAR'],#             type A
            place       => ['SCALAR']#              type A
        }
    ],
    column                      => [#               type K
        'ARRAY',
        'id',
        {
            # PSCALAR means that this element will not
            # be saved. Does not work for YAML yet.
            min         => ['PSCALAR'],#            type A
            max         => ['PSCALAR'],#            type A
            description => ['SCALAR']#              type A
        }
    ],
    axis                        => [#               type F
        'HASH',
        'label',
        {
            unit        => ['SCALAR'],#             type A
            logscale    => ['SCALAR'],#             type A
            description => ['SCALAR']#              type A
        }
    ]
};
#create Lab::Data::XMLtree object from file
$data=Lab::Data::XMLtree->read_xml($data_declaration,'filename.xml')
    ;

#the autoloader
# get
print $data->info_title;
# get with $id
print $data->column_description($id);
# set with $key and $value
$data->axis_description($label,'descriptiontext');

#save data as YAML
$data->save_yaml('filename.yaml');
```

DESCRIPTION

`Lab::Data::XMLtree` will take you to similar spots as XML::Simple does, but in a bigger bus and with fewer wild animals.

That's not a bad thing. You get more control of the data transformation processes and you get some extra functionality.

DATA DECLARATION

Lab::Data::XMLtree uses a data declaration, that describes, what the perl data structure looks like, and how this data structure is converted to XML.

CONSTRUCTORS

new($declaration,[$data]) Create a new Lab::Data::XMLtree. $data must be hashref and should match the declaration. Returns Lab::XMLtree object.

The first two elements define the folding behaviour.

SCALAR|PSCALAR

Element occurs zero or one time. No folding necessary.

Examples:

```
$data->{dataset_title}='content';
```

ARRAY|PARRAY

Element occurs zero or more times. Folding will be done using an array reference. If $id is given, this XML element will be used as an id.

Example:

```
$data->{column}->[4]->{label}='testlabel';
```

HASH|PHASH

Element occurs zero or more times. Folding will be done using a hash reference. If $key is given, this XML element will be used as a key.

Example:

```
$data->{axis}->{gate voltage}->{unit}="mV";
```

read_xml($declaration,$filename) Opens a XML file $filename. Returns Lab::Data::XMLtree object.

read_yaml($declaration,$filename) Opens a YAML file $filename. Returns Lab::Data::XMLtree object.

METHODS

merge_tree($tree) Merge another Lab::Data::XMLtree into this one. Other tree must not necessarily be blessed.

save_xml($filename) Saves the tree as XML to $filename.

save_yaml($filename) Saves the tree as YAML to $filename. PSCALAR etc. don't work yet.

to_string() Returns a stringified version of the object. (Using Data::Dumper.)

autoload Get/set anything you want. Accounts the data declaration.

PRIVATE FUNCTIONS

_load_xml($declaration,$filename)

_merge_node_lists($declaration,$destination_perlnode_list,$source_perlnode_list)

_parse_domnode_list($domnode_list,$defnode_list)

_write_node_list($generator,$defnode_list,$perlnode_list)

_getset_node_list_from_string($perlnode_list,$defnode_list,$nodes_string)

_get_defnode_type($defnode)

_magic_keys($defnode_list,$perlnode_list,$node_name,[@types])

_magic_get_perlnode($defnode_list,$perlnode_list,$node_name,$key,[@types])

_magic_set_perlnode($defnode_list,$perlnode_list,$node_name,$key,$value,[@types])

1.9.5 Lab::Data::Plotter

Plot data with Gnuplot

SYNOPSIS

```
use Lab::Data::Plotter;

my $plotter=new Lab::Data::Plotter($metafile);

my %plots=$plotter->available_plots();
my @names=keys %plots;

$plotter->plot($names[0]);
```

DESCRIPTION

This module can plot data with GnuPlot. It plots data from `.DATA` files and takes into account the data information in the corresponding `.META` file.

The module also offers the possibility to plot data live, while it is being aquired.

CONSTRUCTOR

new

```
$plotter=new Lab::Data::Plotter($meta,\%options);
```

Creates a Plotter object. `$meta` is either an object of type Lab::Data::Meta or a filename that points to a `.META` file.

Available options are

dump

eps

jpg

fulllabels

last_live

METHODS

available_plots

```
my %plots=$plotter->available_plots();
```

plot

```
$plotter->plot($plot);
```

start_live_plot

```
$plotter->start_live_plot($plot);
```

update_live_plot

```
$plotter->update_live_plot();
```

stop_live_plot

```
$plotter->stop_live_plot();
```

1.10 XPRESS

1.10.1 Examples

XPRESS for DUMMIES

Abstract

```
This is a simple, but fully functional Lab::Measurment script,
    which makes use of the XPRESS add-on.
Its purpose as a measurement script is to record a single IV-
    curve. However it is also a step-by-step tutorial (for
    beginners) in writing a XPRESS-style Lab::Measurement script
    .
```

.

Introduction XPRESS is an add-on to Lab::Measurement, that serves several purposes: make writing scripts easy and structured, improve the script readability, save keystrokes and implement a whole bunch of features, that probably would make your scripts really messy if you would have to do it by your own. In order to fulfill those goals, we chose a very modular approach, that enables you to interchange elements within a script, and by that creating a whole new measurement without writing everything from scratch.

There is a simple recipe for a XPRESS style measurment script:

```
Ingredients:

- Measurement instruments
- Sweep Objects
- A Datafile
- Measurement instructions

Throw everything together and start the script.
```

It's really that easy! In the following we would like to show you how to obtain the ingredients and how to put everything in place, using the example of a simple IV-curve measurement.

.

Step by step tutorial - How to write an IV-curve measurement

0. Import Lab::Measurement First thing to do in a script: write the following line

```
use Lab::Measurement;
```

This is how you import the Lab::Measurement library. For basic usage, that's typically everything you need. So you're now ready to start...

1. Measurement instruments For the measurment we need a voltage source and a multimeter to measure the current through our device. Physically the equipment is already next to the computer and connected via National Instruments GPIB interface. But how do we get it into the script? Here is, how it's done for the voltage source (We chose a Yokogawa7651):

```
my $voltage_source = Instrument('Yokogawa7651',
        {
        connection_type => 'VISA_GPIB',
        gpib_address => 5,
        gate_protect => 0
        });
```

The function Instrument() returns the Instrument as a Lab::Measurement object, which we assign to the variable $voltage_source. As first parameter, we have to pass the name of the instrument. The second parameter, the part wrapped in {}, is the configuration hash. This hash should always contain at least the connection_type (here VISA_GPIB) and depending on the connection a corresponding address. Here we use, furthermore, the parameter gate_protect. Gate protection is a really great feature, which comes with Lab::Mesurement, that can help you protecting your samples. But since this is no gate, we don't want to use it now. We just turn it off by setting the parameter to 0. The next example will introduce a gate, and explain the feature in more detail. However, the hash can contain more than that. The available options and parameters can be found in the particular instrument driver documentations. Let's try it on the example of our multimeter:

```
my $multimeter = Instrument('Agilent34410A',
        {
        connection_type => 'VISA_GPIB',
        gpib_address => 3,
        nplc => 10                                          #
            integration time in number of powerline cylces
            [10*(1/50)]
        });
```

In addition to the connection parameters, we specified the integration time of the multimeter, which will be set in the device automatically with the initialization, according to the given value. Those are enough instruments for this simple experiment. Let's get the next ingrediant.

2. Sweep Objects Sweeps are executable objects, which define the basic character of the experiment. Which variable is beeing changed during the experiment, and at which range? How fast is it changed? How often will the experiment be repeated? To create a Sweep Object works very similar to initializing an instrument, but this time using the function Sweep():

```
my $voltage_sweep = Sweep('Voltage',
        {
        instrument => $voltage_source,
        points => [-5e-3, 5e-3],        # [starting point,
            target] in Volts
        rate => [0.1, 0.5e-3],          # [rate to approach
            start, sweeping rate for measurement] in Volts/s
        interval => 1                               # measurement
            interval in s
        });
```

Again we have to specify the type of sweep ('Voltage' here) and a configuration hash. In the config hash we have to pass the Yokogawa as the conducting instrument of the sweep to the parameter instrument. The points parameter defines the starting point and the target of the Sweep in an array. In the rate array, the first value specifies the rate at which the starting point is approached, while the second value defines the rate at which the target will be approached. Here points and rate are of length 2, but one could provide many more, in order to get a complex sweep sequence with changing sweep rates or reversing sweep directions. This is demonstrated in one of the other XPRESS example files. Besides that, there are many other parameters and options available to characterise the sweep, which are documented under the particular types of Sweep.

3. The DataFile In order to log our measurements, we need a DataFile object. It can be obtained using the function DataFile():

```
my $DataFile = DataFile('IVcurve_sample1.dat');
```

where we have to pass the desired filename as first argument. Furthermore, columns have to be defined. For the purpose of the IV-curve, the following 3 are enough.

```
$DataFile->add_column('Voltage');
$DataFile->add_column('Current');
$DataFile->add_column('Resistance');
```

The data will later be logged in the DataFile, corresponding to the order you added the columns. If you wish you can also add a plot to the DataFile, which will refresh live, each time a new data point is logged. In it's simplest form this can look like this:

```
$DataFile->add_plot(
        {
        x-axis => 'Voltage',
        y-axis => 'Current'
        });
```

There are more parameters, that modify the look and type of the plot. Details can be found in the documentation of Lab::XPRESS::Data::XPRESS_DataFile.

4. The measurement instructions As the last ingredient, we have to define how the data values per single measurement are generated. This set of instruction has to be wrapped into a subroutine, which will be executed each second while the sweep is sctive. First, let's have a look on the entire block, before discussing it in detail.

```
my $my_measurement = sub {

        my $sweep = shift;

        my $voltage = $voltage_source->get_value();
        my $current = $multimeter->get_value()*1e-7;
        my $resistance = ($current != 0) ? $voltage/$current : '
            ?';

        $sweep->LOG({
                Voltage => $voltage,
                Current => $current,
                Resistance => $resistance
                });
};
```

Ok now have a closer look:

- `my $my_measurement = sub { ...` -- Here we indicate by the word 'sub', that a new subroutine is created, which instructions, are enclosed by {}. At the same time, the subroutine is assigned to the variable $my_measurement. This allows us to work with it later on.
- `my $sweep = shift;` -- This line delivers us the current sweep object, which is important for propper logging of the data.
- `my $voltage = $voltage_source->get_value();` -- By using the function get_value() of the voltage_source we retrieve the currently applied voltage.
- `my $current = $multimeter->get_value()*1e-7;` -- Same as before, however since we are using a current to voltage converter, we have to multiply the measured value with an amplification factor.
- `my $resistance = ($current != 0) ? $voltage/$current : '?';` -- This looks complicated, well but isn't. You have to read it like: If $current is not zero (?) then $resistance = $voltage / $current. Else (:) $resistance = '?'. This prevents from dividing by 0, which is not allowed. It might be unlikely, that $current is exactly 0, but we don't want to break our script in the middle of a measurement.
- `$sweep->LOG({ Voltage => $voltage, Current => $current, Resistance => $resistance });` -- To store the generated values use $sweep->LOG(). With the hash you put into the function, you connect the freshly measured values with the columns you defined before in your DataFile.
- `};` -- close block and terminate with semicolon

5. Putting everything in place Now we have all ingredients together. But an onion and a potatoe lying side-by-side still make no dish. So, we have to put everything in place. First, the DataFile has to know whats to do to generate a single line of data. That's why, we have to connect our created measurement subroutine with the DataFile:

```
$DataFile->add_measurement($my_measurement);
```

But also, the Sweep has to know the DataFile:

```
$voltage_sweep->add_DataFile($DataFile);
```

The internal process is the following: Every time a measurement should be performed (in our example every second, defined by the interval-parameter of the sweep), the sweep will call all of it's DataFiles (it can have several - i.e. if you have two or more samples -) and command them to log a new line of data. Therefore the DataFile will have to create the data first, using the instructions saved in $my_measurement.

Last but not least, the sweep has to be started:

```
$voltage_sweep->start();
```

Otherwise the script won't do anything. And that's it!

Example 2

Nested Sweeps

Abstract

```
This is a simple, but fully functional Lab::Measurment script,
    which makes use of the XPRESS add-on.
Its purpose as a measurement script is to record a set of IV-
    curves at a series of gate voltages.
However it is also a tutorial, that introduces the XPRESS nested
     Sweeps feature.
Beginners should read Example1 first.
```

.

Introduction Example 1 presented a step by step tutorial in writing simple Lab::Measurement/XPRESS script. In this example we show, how to extend this script, in order to get a set of IV-curves at a series of gate voltages. XPRESS offers a nice feature to implement those extensions in a very simple and mostly already familiar way. In the following, we will focus the new parts of our script and discuss it's meaning.

.

The code

Instrument initialization

```
#-------- 0. Import Lab::Measurement --------

use Lab::Measurement;

#-------- 1. Initialize Instruments --------

my $bias = Instrument('Yokogawa7651',
        {
        connection_type => 'VISA_GPIB',
        gpib_address => 3,
        gate_protect => 0
        });

my $multimeter = Instrument('Agilent34410A',
        {
        connection_type => 'VISA_GPIB',
        gpib_address => 17,
        nplc => 10                                          #
            integration time in number of powerline cylces
            [10*(1/50)]
        });
```

```
my $gate = Instrument('Yokogawa7651',
        {
        connection_type => 'VISA_GPIB',
        gpib_address => 6,

        gate_protect => 1,
        gp_min_units => -10,
        gp_max_units => 15,
        gp_max_units_per_second => 10e-3
        });
```

In this first part of this script, we are doing more or less the same as in Example 1. Import the Lab::Measurement library, then initialize the instruments we need. Now what's new is, that we initialize here a third instrument, the gate, which is again a Yokogawa7651. No big deal, so far. New is, that we are using the gate protection mode this time. It's turned on by <gate_protect = 1>>. With <gp_min_units = -10>> and <gp_max_units = 15>> we define the lower and upper limits, which we do not want to be exceeded by the source instrument. So if the Yokogawa is in voltage sourcing mode (which we expect to be for now), the output Voltage will be limited to values between -10V and 15V. If it would be in current mode, it would not be limited at all, because 15A might be a little bit to much for this device :) With <gp_max_units_per_second = 10e-3>> we define the highest possible sweep rate, so it will sweep no faster than 10mV per second.

Sweep Objects

```
#-------- 2. Define the Sweeps ----------------
my $gate_sweep = Sweep('Voltage',
        {
        mode => 'step',
        instrument => $gate,
        points => [-5, 5],      # [starting point, target] in
            Volts
        stepwidth => [0.1],
        rate => [5e-3],                 # [rate to approach
            start, sweeping rate for measurement] in Volts/s
        });

my $bias_sweep = Sweep('Voltage',
        {
        instrument => $bias,
        points => [-5e-3, 5e-3],        # [starting point,
            target] in Volts
        rate => [0.1, 0.5e-3],          # [rate to approach
            start, sweeping rate for measurement] in Volts/s
        interval => 1,                          # measurement
            interval in s

        delay_before_loop => 10         # delay before Sweep
            begins in s
        });
```

In this experiment, we want to measure the current through our sample, depending on two parameters: the source-drain voltage and the gate voltage. Of course, that means we need instead of only one sweep, now two sweeps. And as you see, we created a second sweep, which we called $gate_sweep. Unlike $source_sweep, this one is in mode 'step'. This means, that instead of sweeping and measuring simultaniously, the instrument will sweep, stop, make a new data value, sweep to the next step ... and so on. And in our case it will be: go to the next step, make an IV-curve and so on. Therefore we have to define the parameter stepwidth, while the rates parameter defines the rate, which is used to approach the steps.

The DataFile

```
#-------- 3. Create a DataFile ---------------

my $DataFile = DataFile('Gate_IV_sample1.dat');

$DataFile->add_column('GateVoltage');
$DataFile->add_column('BiasVoltage');
$DataFile->add_column('Current');
$DataFile->add_column('Resistance');

$DataFile->add_plot({
        'type'     => 'pm3d'

        'x-axis'   => 'GateVoltage',
        'y-axis'   => 'BiasVoltage',
        'cb-axis'  => 'Current'
        });
```

Almost nothing new here, besides: plot-type is now pm3d. This creates a color coded 2D plot. Therefore we have to specify a third axis, the cb-axis, which defines the values, which will be presented color-coded in the plot later on.

4. The measurement instructions

```
#-------- 4. Measurement Instructions -------

my $my_measurement = sub {

        my $sweep = shift;

        my $gate_voltage = $gate->get_value();
        my $bias_voltage = $bias->get_value();
        my $current = $multimeter->get_value()*1e-7;
        my $resistance = ($current != 0) ? $voltage/$current : '
            ?';

        $sweep->LOG({
                GateVoltage => $gate_voltage,
                Voltage => $bias_voltage,
                Current => $current,
                Resistance => $resistance
                });
};
```

Again, almost nothing new here. But its getting really interesting in the next paragraph, so stay with us!

5. Putting everything in place Ok now we are finally, at the heart of this lesson! That's where most of the logic takes place, so we will do it step by step.

```
#-------- 5. Put everything together --------

$DataFile->add_measurement($my_measurement);

$voltage_sweep->add_DataFile($DataFile);
```

We still remember the first two lines. But why is the DataFile only connected to the voltage sweep, and not to the gate sweep? Thats because the voltage sweep is the one, during which the actual measurements take place. But to define which sweep acts first, and which one is controlled by the other one, we introduce a new object. The Frame:

```
my $frame = Frame();
```

You can assign masters and slaves in a frame, just like this:

```
$frame->add_master($gate_sweep);
$frame->add_slave($bias_sweep);
```

The master, has to be a sweep-object, which is in mode 'step' or 'list', here $gate_sweep. Each frame can have only one master. For the slave, you have more freedom. You can put as many slaves as you want into the frame, just by calling add_slave multiple times. It's possible to assign sweep objects of any type as a slave. It's even possible to put your own individual, handwritten code, into the frame as a slave, which will be called each time the master makes a new step. We will show you how to do this in one of the next examples. And you can use another frame as a slave. This way, one can reach an unlimited degree of nesting sweeps, and create experiments, that last years!

Last but not least, as always, you have to start the whole thing. But this time we start the frame instead of one particular sweep:

```
$frame->start();
```

Otherwise the script won't do anything. And that's it!

XPRESS for DUMMIES

Abstract


```
This is a simple, but fully functional Lab::Measurment script,
    which makes use of the XPRESS add-on.
The script will perform a magnetic field sweep and backsweep,
    while measuring the DC resistance of two samples.
The data will be written in two seperate files, one for each
    sample.
```


.

Introduction In this example, the main novelty is the usage of two datafiles, for example to separate the measurements coming from two different samples. Those two files are populated with data, during the same sweep. Besides that, we introduce the magnet type sweep, and a few features, related with the configuration of sweeps.

.

The code

Instrument initialization

```
#-------- 0. Import Lab::Measurement --------

use Lab::Measurement;

#-------- 1. Initialize Instruments --------

my $voltage_source1 = Instrument('Yokogawa7651',
        {
        connection_type => 'VISA_GPIB',
        gpib_address => 3,
        gate_protect => 0
        });

my $multimeter1 = Instrument('Agilent34410A',
        {
        connection_type => 'VISA_GPIB',
        gpib_address => 17,
        nplc => 10                                          #
            integration time in number of powerline cylces
            [10*(1/50)]
        });

my $voltage_source2 = Instrument('Yokogawa7651',
        {
        connection_type => 'VISA_GPIB',
        gpib_address => 5,
        gate_protect => 0
        });
```

```
my $multimeter2 = Instrument('Agilent34410A',
        {
        connection_type => 'VISA_GPIB',
        gpib_address => 11,
        nplc => 10                                          #
            integration time in number of powerline cylces
            [10*(1/50)]
        });

my $magnet = Instrument('IPSWeiss1',
        {
        connection_type => 'IsoBus',
        isobus_address => 2,
        base_connection => Connection('VISA_GPIB', {gpib_address
             => 24})
        });
```

Certainly, it does not come as a surprise to you, that for a magnetic field sweep, we need a instrument, which can control the magnet. Here we use IPSWeiss1, which is an individual child-class of Lab::Instrument::IPS (the Oxford IPS) we use in Regensburg. Since it is connected via IsoBus in this example, the initialization has to be slightly different. Under the term IsoBus we understand, that multiple instruments communicate via the same 'base_connection', but are still individualy accessible using the isobus_address. In order to provide this base_connection, we request directly a connection of type 'VISA_GPIB' with adsress 24.

Sweep Objects

```
#-------- 3. Define the Sweeps ----------

my $magnet_sweep = Sweep('Magnet',
        {
        instrument => $magnet,
        points => [-10, -1, 1, 10],     # [starting point,
            intermediate steps, target] in Tesla
        rate => [1, 0.7, 0.2, 0.7],     # [rate to approach
            start, ... next section, ...,  ... target] in Tesla/
            min
        interval => 1,                          # measurement
            interval in s
        backsweep => 1
        });
```

Now we use (for the first time), the magnet sweep. There are almost no differences to a voltage sweep, but for this script, we used some other features. Most striking is, that 'points' contains more than 2 values. But how can it have more than a start and a target value? The answer is, something changes at those points in between. Here it is the rate, why also the 'rate' array is extended. Now what will happen here is: The field goes from its initial value to -10T at 1T/min, and beginns to sweep to 10T at 0.7T/min. It will change the rate at -1T to 0.2T/min, and at 1T back to 0.7T/min. you can put as many steps into the points array as you want, and even change the

direction within it. If you do not provide enough rates, it will use the last one for the rest of the sequence. Since we define the parameter 'backsweep' to be 1, the sweep will automatically process the sequence in reverted direction, after finishing the original sweep.

The DataFileS

```
#-------- 3. Create a DataFile ----------------

my $DataFile1 = DataFile('MagnFieldSweep_sample1.dat');

$DataFile1->add_column('Field');
$DataFile1->add_column('Voltage');
$DataFile1->add_column('Current');
$DataFile1->add_column('Resistance');

$DataFile1->add_plot({
        'x-axis' => 'Field',
        'y-axis' => 'Resistance'
        });

my $DataFile2 = DataFile('MagnFieldSweep_sample2.dat');

$DataFile2->add_column('Field');
$DataFile2->add_column('Voltage');
$DataFile2->add_column('Current');
$DataFile2->add_column('Resistance');

$DataFile2->add_plot({
        'x-axis' => 'Field',
        'y-axis' => 'Resistance'
        });
```

Just defining two DataFiles, instead of only one. Really nothing interesting here.

4. The measurement instructions However, now since we have two DataFiles, and the first two examples still in mind, the question arises: How can the two DataFiles be addressed individually? The answer is in the following code:

```
my $my_measurement1 = sub {

        my $sweep = shift;

        my $voltage = $voltage_source1->get_value();
        my $current = $multimeter1->get_value()*1e-7;
        my $resistance = ($current != 0) ? $voltage/$current : '
            ?';
```

```
        $sweep->LOG({
                Field => $magnet->get_value()
                }, 0);
                    #<----  0 is the general data space
                                                                    #

                                                                    v
                                                                    p
                                                                    h
                                                                    w
                                                                    b
                                                                    a
                                                                    i
                                                                    b
                                                                    D

        $sweep->LOG({
                Voltage => $voltage,
                Current => $current,
                Resistance => $resistance
                }, 1);
                    #<---- This will be directed to DataFile1
};

my $my_measurement2 = sub {

        my $sweep = shift;

        my $voltage = $voltage_source2->get_value();
        my $current = $multimeter2->get_value()*1e-7;
        my $resistance = ($current != 0) ? $voltage/$current : '
            ?';

        $sweep->LOG({
                Voltage => $voltage,
                Current => $current,
                Resistance => $resistance
                }, 2);
                    #<---- This will be directed to DataFile2
};
```

Of course, both DataFiles should have measurement instructions, since both have to know how to collect the data for a single measurement line. So we got $my_measurement1

and $my_measurement1. By adding the integers 1 or 2 at the end of the LOG instruction, we can specify to which file these data-values should be directed. There is also the option to put the data via LOG into space 0. This data will be available in both files. In this example, we retrieve and log the magnetic field only once in $my_measurement1, since it should be more or less the same for both samples.

5. Putting everything in place It's not hard to gues how to proceed. Of course we have to connect DataFiles with the corresponding measurement instructions:

```
$DataFile1->add_measurement($my_measurement1);
$DataFile2->add_measurement($my_measurement2);
```

And then add the two DataFiles to the sweep, since both should be called each time $magnet_sweep decides it's time for a new measurement point.

```
$magnet_sweep->add_DataFile($DataFile1);
$magnet_sweep->add_DataFile($DataFile2);
```

Last but not least, start the sweep:

```
$magnet_sweep->start();
```

Otherwise the script won't do anything. And that's it!

XPRESS for DUMMIES

Abstract


```
This is a slightly more advanced Lab::Measurment script, which makes
     use of the XPRESS add-on.
The script will perform a nested sweep: For each value of RF power,
    AC conductance is measured for different values of gate voltage
    and RF frequency.
The data will be written in several 2d data files, labeled by the
    the RF power value.
```


.

Introduction In this example, the main novelty is the usage of two nested frames to record a 3-dimensional dataset.

.

The code

Instrument initialization

```
#--------- 1. Initialize Instruments ---------

my $sens =-1e-9;

my $Biasvoltage=-0.01;

my $voltage_bias = Instrument('YokogawaGS200',
    {
    connection_type => 'LinuxGPIB',
    gpib_address => 2,
    gate_protect => 0,
    });

my $voltage_backgate = Instrument('YokogawaGS200',
    {
    connection_type => 'LinuxGPIB',
    gpib_address => 1,
    gate_protect => 0,
    });

my $srs = Instrument('SR830',
        {
     connection_type => 'LinuxGPIB',
     gpib_address  => 14
        });

my $multimeter = Instrument('HP3458A',
    {
    connection_type => 'LinuxGPIB',
    gpib_address => 22,
    nplc => 5
    });
```

```
our $FRQSRC = Instrument('HP83732A',
    {
    connection_type => 'LinuxGPIB',
    gpib_address => 28,

    });

$voltage_bias->set_voltage($Biasvoltage);

$FRQSRC->enable_external_am();

$FRQSRC->power_on();
```

We initialize two Yokos for bias and gate voltage, the SR830 for the AC Lock-in measurement, an Agilent 3458A multimeter (named HP) and a frequency generator. The bias voltage is set immediately after initialization and the frequency generator's output is switched on.

Sweep Objects

```
#-------- 3. Define the Sweeps ----------

my $RF_power_sweep = Sweep('Power',
    {
    mode => 'step',
    instrument => $FRQSRC,
    points => [-15,5],
    stepwidth => 5,
    rate => [5],
    delay_before_loop => 1
    });

my $gate_sweep = Sweep('Voltage',
    {
    mode => 'step',
    instrument => $voltage_backgate,
    points => [5.73,5.81],    # [starting point, target]
    stepwidth => [0.0004],
    rate => [0.05, 0.05],      # [rate to approach start, sweeping
        rate for measurement] in Volts/s
    jump => 1,
    delay_before_loop => 1         # delay before Sweep begins in s
    });

my $RF_frequency_sweep = Sweep('Frequency',
    {
    mode => 'step',
    instrument => $FRQSRC,
    points => [114.5e6, 116.1e6],    # [starting point, target]
    stepwidth => [1.5e3],
    rate => [15000, 15000],      # [rate to approach start, sweeping
        rate for measurement] in Hz/s
    delay_before_loop => 3
    });
```

We want to record conductance on an gate/frequency array for different power values so we have to define three sweep objects: RF power, gate voltage and RF frequency. It might be neccessary to check the duration of the 2d-sweep (gate vs frequency in this case) to carefully choose the amount of steps in RF power. For sweeping RF power, the according sweep object provides only the step mode at the moment. Of course, one can use the "delay_before_loop" flag as well as other default sweep flags (see the documentation of the Sweep base class for details). The gate and frequency sweeps do not contain any novelty. Make sure you specify the frequency in Herz for this sweep object.

The DataFile

```
#-------- 3. Create a DataFile ----------

my $DataFile = DataFile('AC_Power_Gate_Frq.dat');

  $DataFile->add_column('Gate');
  $DataFile->add_column('RF_Frequency');
  $DataFile->add_column('Current');
  $DataFile->add_column('X');
  $DataFile->add_column('Y');
  $DataFile->add_column('R');
  $DataFile->add_column('RF_Power');

$DataFile->add_plot({
    'type' => 'pm3d',
    'x-axis' => 'Gate',
    'y-axis' => 'RF_Frequency',
    'cb-axis' => 'Current',
    'refresh' => 'block'
    }
    );

$DataFile->add_plot({
    'type' => 'pm3d',
    'x-axis' => 'Gate',
    'y-axis' => 'RF_Frequency',
    'cb-axis' => 'R',
    'refresh' => 'block'
    }
    );
```

We provide all variables we are interested in to the datafile object. Note that we do NOT have to define a data file for each value of RF power: This is done automatically. The XPRESS module will add a string to the filename of the form _RF_Power=X. We also add live plots for DC current and AC conductivity.

4. The measurement instructions

```
#-------- 4. Measurement Instructions -------
```

```
my $my_measurement = sub {

    my $sweep = shift;

    my $gate = $voltage_backgate->get_value({read_mode => 'cache'});
    my $RF_Frequency = $FRQSRC->get_frq();
    my $RF_Power = $FRQSRC->get_power();
    my $current = $multimeter->get_value()*$sens;
    my ($X , $Y) = $srs->get_xy();

    $sweep->LOG({
        Gate => $gate,
        RF_Frequency => $RF_Frequency,
        Current => $current,
        X => $X*$sens,
        Y => $Y*$sens,
        R => sqrt($X**2+$Y**2)*$sens,
        RF_Power => $RF_Power
        });
};
```

The measurement instructions have a standard structure. We successively record all data for a single point in the 3-dimensional parameter space. Note that a little time is saved collecting the gate voltage from the software cache of the instrument via {read_mode => 'cache'}. The data is then sent to the LOG routine of the sweep object.

5. Putting everything in place First of all, we have to add the measurement to the DataFile object

```
$DataFile->add_measurement($my_measurement);
```

and associate the data file with the "fast" sweep object, i.e., the sweep object that governs the most volatile parameter. In our case this is the frequency sweep:

```
$RF_frequency_sweep->add_DataFile($DataFile);
```

Finally, there comes the magic of XPRESS. We just define the inner frame object as we would do for a simple 2d scan:

```
my $gateframe=Frame();
$gateframe->add_master($gate_sweep);
$gateframe->add_slave($RF_frequency_sweep);
```

Looks familiar, does it. The outer frame

```
my $powerframe = Frame();
$powerframe->add_master($RF_power_sweep);
$powerframe->add_slave($gateframe);
```

contains the power sweep as master and the other (gate vs. frequency) frame is provided as slave. That's it. We do not have to care about the details or count brackets of for-loops. Last but not least, start the sweep

```
$powerframe->start();

$FRQSRC->disable_external_am();

$FRQSRC->power_off();
```

and switch the frequency generator of once we are done to not heat the sample unneccessarily. Enjoy!

1.10.2 General classes

```
Lab::XPRESS::Sweep::Sweep - base class for Sweeps
```

1.10.3 .

SYNOPSIS

```
Lab::XPRESS::Sweep::Sweep is meant to be used as a base class
    for inheriting Sweeps.
It should not be used directly.
```

.

DESCRIPTION

The Lab::XPRESS::Sweep::Sweep class implements major parts of the Lab::XPRESS framework, a modular way for easy scripting measurements in perl and Lab::Measurement. Direct usage of this class would not result in any action. However it constitutes the fundament for more spezialized subclass Sweeps e.g. Lab::XPRESS::Sweep::Magnet. .

SWEEP PARAMETERS

The configuration parameters are described in the particular subclasses (e.g. Lab::XPRESS::Sweep::Magnet).

.

METHODS

add_DataFile [Lab::XPRESS::Data::XPRESS_DataFile object] use this method to assign a DataFile object with a sweep if it operates as a slave or as a individual sweep. The sweep will call the user-defined measurment routine assigned with the DataFile. Sweeps accept multiple DataFile objects when add_DataFile is used repeatedly.

.

start use this method to execute the sweep.

.

get_value returns by default the current value of the points array or the current step. The method is intended to be overloaded by Sweep-Subclasses, in order to return the current value of the sweeping instrument.

.

LOG [hash, int (default = 0)] use this method to store the data collected by user-defined measurment routine in the DataFile object.

The hash has to look like this: $column_name => $value The column_name has to be one of the previously defined columnames in the DataFile object.

When using multiple DataFile objects within one sweep, you can direct the data hash one of the DataFiles by the second parameter (int). If this parameter is set to 0 (default) the data hash will be directed to all DataFile objects.

Examples: $sweep->LOG({ 'voltage' => 10, 'current' => 1e-6, 'reistance' => $R });

OR:

```
$sweep->LOG({'voltage' => 10});
$sweep->LOG({'current' => 1e-6});
$sweep->LOG({'reistance' => $R});
```

for two DataFiles:

```
# this value will be logged in both DataFiles
$sweep->LOG({'voltage' => 10},0);

# this values will be logged in DataFile 1
$sweep->LOG({
        'current' => 1e-6,
        'reistance' => $R1
},1);

# this values will be logged in DataFile 2
$sweep->LOG({
        'current' => 10e-6,
        'reistance' => $R2
},2);
```

.

last use this method, in order to stop the current sweep. Example:

```
# Stop a voltage Sweep if device current exeeds a critical limit
    .

if ($current > $high_limit) {
        $voltage_sweep->last();
}
```

.

HOW TO DEVELOP SUBCLASS OF Lab::XPRESS::Sweep::Sweep

preefine the default_config hash values in method 'new':

```
sub new {
    my $proto = shift;
        my @args=@_;
    my $class = ref($proto) || $proto;
        my $self->{default_config} = {
                id => 'Magnet_sweep',
                filename_extension => 'B=',
                interval         => 1,
                points  =>       [],
                duration         => [],
                mode     => 'continuous',
                allowed_instruments => ['Lab::Instrument::IPS',
                    'Lab::Instrument::IPSWeiss1', 'Lab::
                    Instrument::IPSWeiss2', 'Lab::Instrument::
                    IPSWeissDilIFridge'],
                allowed_sweep_modes => ['continuous', 'list', '
                    step'],
                number_of_points => [undef]
                };

        $self = $class->SUPER::new($self->{default_config},@args
            );
        bless ($self, $class);

    return $self;
}
```

the following methodes have to be overloaded in the subclass:

```
sub go_to_sweep_start{}
sub start_continuous_sweep{}
sub go_to_next_step{}
sub exit_loop{}
sub get_value{}
sub exit{}
```

additionally see one of the present Sweep-Subclasses.
.

```
Lab::XPRESS::Sweep::Frame -
```

1.10.4 .

SYNOPSIS

```
use Lab::XPRESS::hub;
my $hub = new Lab::XPRESS::hub();

my $frame = $hub->Frame();

$frame->add_master($sweep_0);

$frame->add_slave($sweep_1);
$frame->add_slave($sweep_2);
$frame->add_slave($sweep_3);

$frame->start();
```

.

DESCRIPTION

Parent: Lab::XPRESS::Sweep::Sweep

The Lab::XPRESS::Sweep::Frame class implements a module to organize a nested sweep structure in the Lab::XPRESS::Sweep framework.

The Frame object has no parameters. .

CONSTRUCTOR

```
my $frame = $hub->Frame();
```

Instantiates a new Frame object.

.

METHODS

add_master

```
$frame->add_master($sweep);
```

use this methode to add a master sweep to the frame object. A Frame accepts only a single master sweep.

.

add_slave

```
$frame->add_slave($sweep);
```

use this methode to add a slave sweep to the frame object. A Frame can have several slave sweeps.

The order in which the slave sweeps are added to the frame object, defines the sequence in which the individual slave sweeps will be executed.

```
$frame->add_slave($sweep_1);
$frame->add_slave($sweep_2);
$frame->add_slave($sweep_3);
```

The frame object accepts also another frame object as a slave sweep. This way you can build up a multi level nested sweep structure.

```
my $inner_frame = $hub->Frame();
my $outer_frame = $hub->Frame();

$inner_frame->add_master($sweep_0);

$inner_frame->add_slave($sweep_1);
$inner_frame->add_slave($sweep_2);
$inner_frame->add_slave($sweep_3);

$outer_frame->add_master($sweep_10);

$outer_frame->add_slave($sweep_11);
$outer_frame->add_slave($inner_frame);
$outer_frame->add_slave($sweep_11);

$outer_frame->start();
```

.

start

```
$frame->start();
```

use this methode to execute the nested sweeps.

1.10.5 Dedicated Sweep Classes

```
Lab::XPRESS::Sweep::Magnet - magnetic field sweep
```

1.10.6 .

SYNOPSIS

```
use Lab::XPRESS::hub;
my $hub = new Lab::XPRESS::hub();

my $IPS = $hub->Instrument('IPS',
        {
        connection_type => 'VISA_GPIB',
        gpib_address => 24
        });

my $sweep_magnet = $hub->Sweep('Magnet',
        {
        instrument => $IPS,
        points => [-10,10],
        rate => [1.98,1],
        mode => 'continuous',
        interval => 1,
        backsweep => 1
        });
```

.

DESCRIPTION

Parent: Lab::XPRESS::Sweep::Sweep

The Lab::XPRESS::Sweep::Magnet class implements a module for magnetic field Sweeps in the Lab::XPRESS::Sweep framework.

.

CONSTRUCTOR

```
my $sweep_magnet = $hub->Sweep('Magnet',
        {
        instrument => $IPS,
        points => [-10,10],
        rate => [1.98,1],
        mode => 'continuous',
        interval => 1,
        backsweep => 1
        });
```

Instantiates a new Magnet-sweep.

.

SWEEP PARAMETERS

instrument [Lab::Instrument] (mandatory) Instrument, conducting the sweep. Must be of type Lab:Instrument. Allowed instruments: Lab::Instrument::IPS, Lab::Instrument::IPSWeiss1, Lab::Instrument::IPSWeiss2, Lab::Instrument::IPSWeissDillFridge

.

mode [string] (default = 'continuous' | 'step' | 'list') continuous: perform a continuous magnetic field sweep. Measurements will be performed constantly at the time-interval defined in interval.

step: measurements will be performed at discrete values of the magnetic field between start and end points defined in parameter points, seperated by the magnetic field values defined in parameter stepwidth

list: measurements will be performed at a list of magnetic field values defined in parameter points

.

points [float array] (mandatory) array of magnetic field values (in Tesla) that defines the characteristic points of the sweep. First value is appraoched before measurement begins.

Case mode => 'continuous' : List of at least 2 values, that define start and end point of the sweep or a sequence of consecutive sweep-sections (e.g. if changing the sweep-rate for different sections or reversing the sweep direction). points => [-5, 5] # Start: -5 / Stop: 5

```
points => [-5, -1, 1, 5]

points => [0, -5, 5]
```

Case mode => 'step' : Same as in 'continuous' but magnetic field will be swept in stop and go mode. I.e. Magnet approaches field values between start and stop at the interval defined in 'stepwidth'. A measurement is performed, when magnet is idle.

Case mode => 'list' : Array of magnetic field values, with minimum length 1, that are approached in sequence to perform a measurment.

.

rate [float array] (mandatory if not defined duration) array of rates, at which the magnetic field is swept (Tesla / min). Has to be of length 1 or greater (Maximum length: length of points-array). The first value defines the rate to approach the starting point. The following values define the rates to approach the magnetic field values defined by the points-array. If the number of values in the rates-array is less than the length of the points-array, the last defined rate will be used for the remaining sweep sections.

```
points => [-5, -1, 1, 5],
rates => [1, 0.5, 0.2]

rate to approach -5 T (the starting point): 1 T/min
rate to approach -1 T  : 0.5 T/min
rate to approach 1 T  : 0.2 T/min
rate to approach 5 T   : 0.2 T/min (last defined rate)
```

.

duration [float array] (mandatory if not defined rate) can be used instead of 'rate'. Attention: Use only the 'duration' or the 'rate' parameter. Using both will cause an Error!

The first value defines the duration to approach the starting point. The second value defines the duration to approach the magnetic field value defined by the second value of the points-array. ... If the number of values in the duration-array is less than the length of the points-array, last defined duration will be used for the remaining sweep sections.

.

stepwidth [float array] This parameter is relevant only if mode = 'step' has been selected. Stepwidth has to be an array of length '1' or greater. The values define the width for each step within the corresponding sweep sequence. If the length of the defined sweep sequence devided by the stepwidth is not an integer number, the last step will be smaller in order to reach the defined points-value.

```
points = [0, 0.5, 3]
stepwidth = [0.2, 0.5]

==> steps: 0, 0.2, 0.4, 0.5, 1.0, 1.5, 2.0, 2.5, 3
```

.

number_of_points [int array] can be used instead of 'stepwidth'. Attention: Use only the 'number_of_points' or the 'stepwidth' parameter. Using both will cause an Error! This parameter is relevant only if mode = 'step' has been selected. Number_of_points has to be an array of length '1' or greater. The values defines the number of steps within the corresponding sweep sequence.

```
points = [0, 0.5, 3]
number_of_points = [5, 2]

==> steps: 0, 0.1, 0.2, 0.3, 0.4, 0.5, 1.75, 3
```

.

interval [float] (default = 1) interval in seconds for taking measurement points. Only relevant in mode 'continuous'.

.

backsweep [int] (default = 0 | 1 | 2) 0 : no backsweep (default) 1 : a backsweep will be performed 2 : no backsweep performed automatically, but sweep sequence will be reverted every second time the sweep is started (relevant eg. if sweep operates as a slave. This way the sweep sequence is reverted at every second step of the master)

.

id [string] (default = 'Magnet_sweep') Just an ID.

.

filename_extention [string] (default = 'B=') Defines a postfix, that will be appended to the filenames if necessary.

.

delay_before_loop [int] (default = 0) defines the time in seconds to wait after the starting point has been reached.

.

delay_in_loop [int] (default = 0) This parameter is relevant only if mode = 'step' or 'list' has been selected. Defines the time in seconds to wait after the value for the next step has been reached.

.

delay_after_loop [int] (default = 0) Defines the time in seconds to wait after the sweep has been finished. This delay will be executed before an optional backsweep or optional repetitions of the sweep.

.

```
Lab::XPRESS::Sweep::Voltage - voltage sweep
```

1.10.7 .

SYNOPSIS

```
use Lab::XPRESS::hub;
my $hub = new Lab::XPRESS::hub();

my $Yoki = $hub->Instrument('Yokogawa7651',
        {
        connection_type => 'VISA_GPIB',
        gpib_address => 2
        });

my $sweep_voltage = $hub->Sweep('Voltage',
        {
        instrument => $Yoki,
        points => [-1,1],
        rate => [0.1,0.001],
        mode => 'continuous',
        interval => 1,
        backsweep => 1
        });
```

.

DESCRIPTION

Parent: Lab::XPRESS::Sweep::Sweep

The Lab::XPRESS::Sweep::Voltage class implements a module for voltage Sweeps in the Lab::XPRESS::Sweep framework.

.

CONSTRUCTOR

```
my $sweep_voltage = $hub->Sweep('Voltage',
        {
        instrument => $Yoki,
        points => [-1,1],
        rate => [0.1,0.001],
        mode => 'continuous',
        interval => 1,
        backsweep => 1
        });
```

Instantiates a new voltage-sweep.

.

PARAMETERS

instrument [Lab::Instrument] (mandatory) Instrument, conducting the sweep. Must be of type Lab:Instrument. Allowed instruments: Lab::Instrument::Yokogawa7651

.

mode [string] (default = 'continuous' | 'step' | 'list') continuous: perform a continuous voltage sweep. Measurements will be performed constantly at the time-interval defined in interval.

step: measurements will be performed at discrete values of the applied voltage between start and end points defined in parameter points, seperated by voltage steps defined in parameter stepwidth

list: measurements will be performed at a list voltage values defined in parameter points

.

points [float array] (mandatory) array of voltage values (in volts) that defines the characteristic points of the sweep. First value is appraoched before measurement begins.

Case mode => 'continuous' : List of at least 2 values, that define start and end point of the sweep or a sequence of consecutive sweep-sections (e.g. if changing the sweep-rate for different sections or reversing the sweep direction). points => [-5, 5] # Start: -5 / Stop: 5

```
points => [-5, -1, 1, 5]

points => [0, -5, 5]
```

Case mode => 'step' : Same as in 'continuous' but voltage will be swept in stop and go mode. I.e. voltage source approaches values between start and stop at the interval defined in 'stepwidth'. A measurement is performed, when voltage source is idle.

Case mode => 'list' : Array of voltages, with minimum length 1, that are approached in sequence to perform a measurment.

.

rate [float array] (mandatory if not defined duration) array of rates, at which the voltage is swept (V / sec). Has to be of length 1 or greater (Maximum length: length of points-array). The first value defines the rate to approach the starting point. The following values define the rates to approach the voltages defined by the points-array. If the number of values in the rates-array is less than the length of the points-array, the last defined rate will be used for the remaining sweep sections.

```
points => [-5, -1, 1, 5],
rates => [1, 0.005, 0.02]
```

```
rate to approach -5 V (the starting point): 1 V/sec
rate to approach -1 V  : 0.005 V/sec
rate to approach 1 V   : 0.02 V/sec
rate to approach 5 V   : 0.02 V/sec (last defined rate)
```

.

duration [float array] (mandatory if not defined rate) can be used instead of 'rate'. Attention: Use only the 'duration' or the 'rate' parameter. Using both will cause an Error!

The first value defines the duration to approach the starting point. The second value defines the duration to approach the voltage value defined by the second value of the points-array. ... If the number of values in the duration-array is less than the length of the points-array, last defined duration will be used for the remaining sweep sections.

.

stepwidth [float array] This parameter is relevant only if mode = 'step' has been selected. Stepwidth has to be an array of length '1' or greater. The values define the width for each step within the corresponding sweep sequence. If the length of the defined sweep sequence devided by the stepwidth is not an integer number, the last step will be smaller in order to reach the defined points-value.

```
points = [0, 0.5, 3]
stepwidth = [0.2, 0.5]

==> steps: 0, 0.2, 0.4, 0.5, 1.0, 1.5, 2.0, 2.5, 3
```

.

number_of_points [int array] can be used instead of 'stepwidth'. Attention: Use only the 'number_of_points' or the 'stepwidth' parameter. Using both will cause an Error! This parameter is relevant only if mode = 'step' has been selected. Number_of_points has to be an array of length '1' or greater. The values defines the number of steps within the corresponding sweep sequence.

```
points = [0, 0.5, 3]
number_of_points = [5, 2]

==> steps: 0, 0.1, 0.2, 0.3, 0.4, 0.5, 1.75, 3
```

.

interval [float] (default = 1) interval in seconds for taking measurement points. Only relevant in mode 'continuous'.

.

backsweep [int] (default = 0 | 1 | 2) 0 : no backsweep (default) 1 : a backsweep will be performed 2 : no backsweep performed automatically, but sweep sequence will be reverted every second time the sweep is started (relevant eg. if sweep operates as a slave. This way the sweep sequence is reverted at every second step of the master)

.

jump [int] (default = 0 | 1) can be used to switch off the sweeping between adjacent points in step or list mode.

0 : a sweep is performed between adjacent steps (default) 1 : the voltage is set without sweeping, given that gateprotect does not trigger a sweep.

.

id [string] (default = 'Voltage_sweep') Just an ID.

.

filename_extention [string] (default = 'V=') Defines a postfix, that will be appended to the filenames if necessary.

.

delay_before_loop [int] (default = 0) defines the time in seconds to wait after the starting point has been reached.

.

delay_in_loop [int] (default = 0) This parameter is relevant only if mode = 'step' or 'list' has been selected. Defines the time in seconds to wait after the value for the next step has been reached.

.

delay_after_loop [int] (default = 0) Defines the time in seconds to wait after the sweep has been finished. This delay will be executed before an optional backsweep or optional repetitions of the sweep.

.

```
Lab::XPRESS::Sweep::Time - simple time controlled repeater
```

1.10.8 .

SYNOPSIS

```
use Lab::XPRESS::hub;
my $hub = new Lab::XPRESS::hub();

my $repeater = $hub->Sweep('Time',
        {
        duration => 5
        });
```

.

DESCRIPTION

Parent: Lab::XPRESS::Sweep::Sweep

The Lab::XPRESS::Sweep::Time class implements a simple time controlled repeater module in the Lab::XPRESS::Sweep framework.

.

CONSTRUCTOR

```
my $repeater = $hub->Sweep('Time',
        {
        repetitions => 5
        });
```

Instantiates a new Repeater.

.

PARAMETERS

duration [int] (default = 1) duration for the time controlled repeater. Default value is 1, negative values indicate a infinit number of repetitions.

.

interval [int] (default = 1) interval in seconds for taking measurement points.

.

id [string] (default = 'Repeater') Just an ID.

.

delay_before_loop [int] (default = 0) defines the time in seconds to wait after the starting point has been reached.

.

delay_after_loop [int] (default = 0) Defines the time in seconds to wait after the sweep has been finished. This delay will be executed before an optional backsweep or optional repetitions of the sweep.

.

```
Lab::XPRESS::Sweep::Motor - stepper motor sweep
```

1.10.9 .

SYNOPSIS

```
use Lab::XPRESS::hub;
my $hub = new Lab::XPRESS::hub();

my $stepper = $hub->Instrument('PDPD11042',
        {
        connection_type => 'VISA_RS232',
        gpib_address => 2
        });

my $sweep_motor = $hub->Sweep('Motor',
        {
        instrument => $stepper,
        points => [-10,10],
        rate => [1.98,1],
        mode => 'continuous',
        interval => 1,
        backsweep => 1
        });
```

.

DESCRIPTION

Parent: Lab::XPRESS::Sweep::Sweep

The Lab::XPRESS::Sweep::Motor class implements a module for stepper motor sweeps in the Lab::XPRESS::Sweep framework.

.

CONSTRUCTOR

```
my $sweep_motor = $hub->Sweep('Motor',
        {
        instrument => $stepper,
        points => [-10,10],
        rate => [1.98,1],
        mode => 'continuous',
        interval => 1,
        backsweep => 1
        });
```

Instantiates a new stepper motor sweep

.

SWEEP PARAMETERS

instrument [Lab::Instrument] (mandatory) Instrument, conducting the sweep. Must be of type Lab:Instrument. Allowed instruments: Lab::Instrument::PD11042, Lab::Instrument::ProSte

.

mode [string] (default = 'continuous' | 'step' | 'list') continuous: perform a continuous stepper motor sweep. Measurements will be performed constantly at the time-interval defined in interval.

step: measurements will be performed at discrete values between start and end points defined in parameter points, seperated by a step defined in parameter stepwidth

list: measurements will be performed at a list of values defined in parameter points

.

points [float array] (mandatory) array of values (in deg) that defines the characteristic points of the sweep. First value is appraoched before measurement begins.

Case mode => 'continuous' : List of at least 2 values, that define start and end point of the sweep or a sequence of consecutive sweep-sections (e.g. if changing the sweep-rate for different sections or reversing the sweep direction). points => [0, 180] # Start: 0 / Stop: 180

```
points => [0, 90, 180, 360]

points => [0, -90, 90]
```

Case mode => 'step' : Same as in 'continuous' but stepper motor will be swept in stop and go mode. I.e. stepper motor approaches values between start and stop at the interval defined in 'stepwidth'. A measurement is performed, when the motor is idle.

Case mode => 'list' : Array of values, with minimum length 1, that are approached in sequence to perform a measurment.

.

rate [float array] (mandatory if not defined duration) array of rates, at which the stepper motor is swept (deg / min). Has to be of length 1 or greater (Maximum length: length of points-array). The first value defines the rate to approach the starting point. The following values define the rates to approach the values defined by the points-array. If the number of values in the rates-array is less than the length of the points-array, the last defined rate will be used for the remaining sweep sections.

```
points => [-90, 0, 90, 180],
rates => [1, 0.5, 0.2]

rate to approach -90 deg (the starting point): 1 deg/min
rate to approach 0 deg  : 0.5 deg/min
rate to approach 90 deg  : 0.2 deg/min
rate to approach 180 deg   : 0.2 deg/min (last defined rate)
```

.

duration [float array] (mandatory if not defined rate) can be used instead of 'rate'. Attention: Use only the 'duration' or the 'rate' parameter. Using both will cause an Error!

The first value defines the duration to approach the starting point. The second value defines the duration to approach the value defined by the second value of the points-array. ... If the number of values in the duration-array is less than the length of the points-array, last defined duration will be used for the remaining sweep sections.

.

stepwidth [float array] This parameter is relevant only if mode = 'step' has been selected. Stepwidth has to be an array of length '1' or greater. The values define the width for each step within the corresponding sweep sequence. If the length of the defined sweep sequence devided by the stepwidth is not an integer number, the last step will be smaller in order to reach the defined points-value.

```
points = [0, 90, 180]
stepwidth = [10, 25]

==> steps: 0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 115, 140, 165,
    180
```

.

number_of_points [int array] can be used instead of 'stepwidth'. Attention: Use only the 'number_of_points' or the 'stepwidth' parameter. Using both will cause an Error! This parameter is relevant only if mode = 'step' has been selected. Number_of_points has to be an array of length '1' or greater. The values defines the number of steps within the corresponding sweep sequence.

```
points = [0, 90, 180]
number_of_points = [5, 2]

==> steps: 0, 18, 36, 54, 72, 90, 135, 180
```

.

interval [float] (default = 1) interval in seconds for taking measurement points. Only relevant in mode 'continuous'.

.

backsweep [int] (default = 0 | 1 | 2) 0 : no backsweep (default) 1 : a backsweep will be performed 2 : no backsweep performed automatically, but sweep sequence will be reverted every second time the sweep is started (relevant eg. if sweep operates as a slave. This way the sweep sequence is reverted at every second step of the master)

.

id [string] (default = 'Motor_sweep') Just an ID.

.

filename_extention [string] (default = 'PHI=') Defines a postfix, that will be appended to the filenames if necessary.

.

delay_before_loop [int] (default = 0) defines the time in seconds to wait after the starting point has been reached.

.

delay_in_loop [int] (default = 0) This parameter is relevant only if mode = 'step' or 'list' has been selected. Defines the time in seconds to wait after the value for the next step has been reached.

.

delay_after_loop [int] (default = 0) Defines the time in seconds to wait after the sweep has been finished. This delay will be executed before an optional backsweep or optional repetitions of the sweep.

.

```
Lab::XPRESS::Sweep::Repeater - simple repeater
```

1.10.10 .

SYNOPSIS

```
use Lab::XPRESS::hub;
my $hub = new Lab::XPRESS::hub();

my $repeater = $hub->Sweep('Repeater',
        {
        repetitions => 5
        });
```

.

DESCRIPTION

Parent: Lab::XPRESS::Sweep::Sweep

The Lab::XPRESS::Sweep::Repeater class implements a simple repeater module in the Lab::XPRESS::Sweep framework.

.

CONSTRUCTOR

```
my $repeater = $hub->Sweep('Repeater',
        {
        repetitions => 5
        });
```

Instantiates a new Repeater.

.

PARAMETERS

repetitions [int] (default = 1) number of repetitions. default value is 1, negative values indicate a infinit number of repetitions.

.

id [string] (default = 'Repeater') Just an ID.

.

filename_extention [string] (default = '#=') Defines a postfix, that will be appended to the filenames if necessary.

.

delay_before_loop [int] (default = 0) defines the time in seconds to wait after the starting point has been reached.

.

delay_in_loop [int] (default = 0) This parameter is relevant only if mode = 'step' or 'list' has been selected. Defines the time in seconds to wait after the value for the next step has been reached.

.

delay_after_loop [int] (default = 0) Defines the time in seconds to wait after the sweep has been finished. This delay will be executed before an optional backsweep or optional repetitions of the sweep.

.

```
Lab::XPRESS::Sweep::Temperature - temperature sweep
```

1.10.11 .

SYNOPSIS

```
use Lab::XPRESS::hub;
my $hub = new Lab::XPRESS::hub();

my $tsensor = $hub->Instrument('ITC',
        {
        connection_type => 'VISA_RS232',
        gpib_address => 2
        });

my $sweep_temperature = $hub->Sweep('Temperature',
        {
        instrument => $tsensor,
        points => [90,4],
        mode => 'list'
        });
```

.

DESCRIPTION

Parent: Lab::XPRESS::Sweep::Sweep

The Lab::XPRESS::Sweep::Temperature class implements a module for temperature sweeps in the Lab::XPRESS::Sweep framework.

.

CONSTRUCTOR

```
my $sweep_temperature = $hub->Sweep('Temperature',
        {
        instrument => $tsensor,
        points => [90,4],
        mode => 'list'
        });
```

Instantiates a new temperature sweep

.

PARAMETERS

instrument [Lab::Instrument] (mandatory) Instrument, conducting the sweep. Must be of type Lab:Instrument. Supported instruments: Lab::Instrument::ITC

.

mode [string] (default = 'continuous' | 'step' | 'list') continuous: perform a continuous temperature sweep. After the starting temperature has been stabalized by the temperature controller, the heater will be switched off in order to cool down to the final value. Measurements will be performed constantly at the time-interval defined in interval.

step: measurements will be performed at discrete values between start and end points defined in parameter points, seperated by a step defined in parameter stepwidth

list: measurements will be performed at a list of values defined in parameter points

.

points [float array] (mandatory) array of values (in deg) that defines the characteristic points of the sweep. First value is appraoched before measurement begins.

Case mode => 'continuous' : List of exactly 2 values, that define start and end point of the sweep. The starting point has to be higher value than the endpont. points => [180, 4] # Start: 180 K / Stop: 4 K

Case mode => 'step' : Same as in 'continuous' but the temperature controller will stabalize the temperature at the defined setpoints. A measurement is performed, when the motor is idle.

Case mode => 'list' : Array of values, with minimum length 1, that are approached in sequence to perform a measurment.

.

stepwidth [float array] This parameter is relevant only if mode = 'step' has been selected. Stepwidth has to be an array of length '1' or greater. The values define the width for each step within the corresponding sweep sequence. If the length of the defined sweep sequence devided by the stepwidth is not an integer number, the last step will be smaller in order to reach the defined points-value.

```
points = [0, 90, 180]
stepwidth = [10, 25]

==> steps: 0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 115, 140, 165,
    180
```

.

number_of_points [int array] can be used instead of 'stepwidth'. Attention: Use only the 'number_of_points' or the 'stepwidth' parameter. Using both will cause an Error! This parameter is relevant only if mode = 'step' has been selected. Number_of_points has to be an array of length '1' or greater. The values defines the number of steps within the corresponding sweep sequence.

```
points = [0, 90, 180]
number_of_points = [5, 2]
```

```
==> steps: 0, 18, 36, 54, 72, 90, 135, 180
```

.

interval [float] (default = 1) interval in seconds for taking measurement points. Only relevant in mode 'continuous'.

.

id [string] (default = 'Temperature_sweep') Just an ID.

.

filename_extention [string] (default = 'T=') Defines a postfix, that will be appended to the filenames if necessary.

.

delay_before_loop [int] (default = 0) defines the time in seconds to wait after the starting point has been reached.

.

delay_in_loop [int] (default = 0) This parameter is relevant only if mode = 'step' or 'list' has been selected. Defines the time in seconds to wait after the value for the next step has been reached.

.

delay_after_loop [int] (default = 0) Defines the time in seconds to wait after the sweep has been finished. This delay will be executed before an optional backsweep or optional repetitions of the sweep.

.

```
Lab::XPRESS::Sweep::Sweep - base class for Sweeps
```

1.10.12 .

SYNOPSIS

```
Lab::XPRESS::Sweep::Sweep is meant to be used as a base class
    for inheriting Sweeps.
It should not be used directly.
```

.

DESCRIPTION

The Lab::XPRESS::Sweep::Sweep class implements major parts of the Lab::XPRESS framework, a modular way for easy scripting measurements in perl and Lab::Measurement. Direct usage of this class would not result in any action. However it constitutes the fundament for more spezialized subclass Sweeps e.g. Lab::XPRESS::Sweep::Magnet. .

SWEEP PARAMETERS

The configuration parameters are described in the particular subclasses (e.g. Lab::XPRESS::Sweep::Magnet).

.

METHODS

add_DataFile [Lab::XPRESS::Data::XPRESS_DataFile object] use this method to assign a DataFile object with a sweep if it operates as a slave or as a individual sweep. The sweep will call the user-defined measurment routine assigned with the DataFile. Sweeps accept multiple DataFile objects when add_DataFile is used repeatedly.

.

start use this method to execute the sweep.

.

get_value returns by default the current value of the points array or the current step. The method is intended to be overloaded by Sweep-Subclasses, in order to return the current value of the sweeping instrument.

.

LOG [hash, int (default = 0)] use this method to store the data collected by user-defined measurment routine in the DataFile object.

The hash has to look like this: $column_name => $value The column_name has to be one of the previously defined columnames in the DataFile object.

When using multiple DataFile objects within one sweep, you can direct the data hash one of the DataFiles by the second parameter (int). If this parameter is set to 0 (default) the data hash will be directed to all DataFile objects.

Examples: $sweep->LOG({ 'voltage' => 10, 'current' => 1e-6, 'reistance' => $R });

OR:

```
$sweep->LOG({'voltage' => 10});
$sweep->LOG({'current' => 1e-6});
$sweep->LOG({'reistance' => $R});
```

for two DataFiles:

```
# this value will be logged in both DataFiles
$sweep->LOG({'voltage' => 10},0);

# this values will be logged in DataFile 1
$sweep->LOG({
        'current' => 1e-6,
        'reistance' => $R1
},1);

# this values will be logged in DataFile 2
$sweep->LOG({
        'current' => 10e-6,
        'reistance' => $R2
},2);
```

.

last use this method, in order to stop the current sweep. Example:

```
# Stop a voltage Sweep if device current exeeds a critical limit
    .

if ($current > $high_limit) {
        $voltage_sweep->last();
}
```

.

HOW TO DEVELOP SUBCLASS OF Lab::XPRESS::Sweep::Sweep

preefine the default_config hash values in method 'new':

```
sub new {
    my $proto = shift;
        my @args=@_;
    my $class = ref($proto) || $proto;
        my $self->{default_config} = {
                id => 'Magnet_sweep',
                filename_extension => 'B=',
                interval         => 1,
                points  =>       [],
                duration         => [],
                mode     => 'continuous',
                allowed_instruments => ['Lab::Instrument::IPS',
                    'Lab::Instrument::IPSWeiss1', 'Lab::
                    Instrument::IPSWeiss2', 'Lab::Instrument::
                    IPSWeissDilIFridge'],
                allowed_sweep_modes => ['continuous', 'list', '
                    step'],
                number_of_points => [undef]
                };

        $self = $class->SUPER::new($self->{default_config},@args
            );
        bless ($self, $class);

    return $self;
}
```

the following methodes have to be overloaded in the subclass:

```
sub go_to_sweep_start{}
sub start_continuous_sweep{}
sub go_to_next_step{}
sub exit_loop{}
sub get_value{}
sub exit{}
```

additionally see one of the present Sweep-Subclasses.
.

```
Lab::XPRESS::Sweep::Frame -
```

1.10.13 .

SYNOPSIS

```
use Lab::XPRESS::hub;
my $hub = new Lab::XPRESS::hub();

my $frame = $hub->Frame();

$frame->add_master($sweep_0);

$frame->add_slave($sweep_1);
$frame->add_slave($sweep_2);
$frame->add_slave($sweep_3);

$frame->start();
```

.

DESCRIPTION

Parent: Lab::XPRESS::Sweep::Sweep

The Lab::XPRESS::Sweep::Frame class implements a module to organize a nested sweep structure in the Lab::XPRESS::Sweep framework.

The Frame object has no parameters. .

CONSTRUCTOR

```
my $frame = $hub->Frame();
```

Instantiates a new Frame object.

.

METHODS

add_master

```
$frame->add_master($sweep);
```

use this methode to add a master sweep to the frame object. A Frame accepts only a single master sweep.

.

add_slave

```
$frame->add_slave($sweep);
```

use this methode to add a slave sweep to the frame object. A Frame can have several slave sweeps.

The order in which the slave sweeps are added to the frame object, defines the sequence in which the individual slave sweeps will be executed.

```
$frame->add_slave($sweep_1);
$frame->add_slave($sweep_2);
$frame->add_slave($sweep_3);
```

The frame object accepts also another frame object as a slave sweep. This way you can build up a multi level nested sweep structure.

```
my $inner_frame = $hub->Frame();
my $outer_frame = $hub->Frame();

$inner_frame->add_master($sweep_0);

$inner_frame->add_slave($sweep_1);
$inner_frame->add_slave($sweep_2);
$inner_frame->add_slave($sweep_3);

$outer_frame->add_master($sweep_10);

$outer_frame->add_slave($sweep_11);
$outer_frame->add_slave($inner_frame);
$outer_frame->add_slave($sweep_11);

$outer_frame->start();
```

.

start

```
$frame->start();
```

use this methode to execute the nested sweeps.

```
Lab::XPRESS::Sweep::Magnet - magnetic field sweep
```

1.10.14 .

SYNOPSIS

```
use Lab::XPRESS::hub;
my $hub = new Lab::XPRESS::hub();

my $IPS = $hub->Instrument('IPS',
        {
        connection_type => 'VISA_GPIB',
        gpib_address => 24
        });

my $sweep_magnet = $hub->Sweep('Magnet',
        {
        instrument => $IPS,
        points => [-10,10],
        rate => [1.98,1],
        mode => 'continuous',
        interval => 1,
        backsweep => 1
        });
```

.

DESCRIPTION

Parent: Lab::XPRESS::Sweep::Sweep

The Lab::XPRESS::Sweep::Magnet class implements a module for magnetic field Sweeps in the Lab::XPRESS::Sweep framework.

.

CONSTRUCTOR

```
my $sweep_magnet = $hub->Sweep('Magnet',
        {
        instrument => $IPS,
        points => [-10,10],
        rate => [1.98,1],
        mode => 'continuous',
        interval => 1,
        backsweep => 1
        });
```

Instantiates a new Magnet-sweep.

.

SWEEP PARAMETERS

instrument [Lab::Instrument] (mandatory) Instrument, conducting the sweep. Must be of type Lab:Instrument. Allowed instruments: Lab::Instrument::IPS, Lab::Instrument::IPSWeiss1, Lab::Instrument::IPSWeiss2, Lab::Instrument::IPSWeissDillFridge

.

mode [string] (default = 'continuous' | 'step' | 'list') continuous: perform a continuous magnetic field sweep. Measurements will be performed constantly at the time-interval defined in interval.

step: measurements will be performed at discrete values of the magnetic field between start and end points defined in parameter points, seperated by the magnetic field values defined in parameter stepwidth

list: measurements will be performed at a list of magnetic field values defined in parameter points

.

points [float array] (mandatory) array of magnetic field values (in Tesla) that defines the characteristic points of the sweep. First value is appraoched before measurement begins.

Case mode => 'continuous' : List of at least 2 values, that define start and end point of the sweep or a sequence of consecutive sweep-sections (e.g. if changing the sweep-rate for different sections or reversing the sweep direction). points => [-5, 5] # Start: -5 / Stop: 5

```
points => [-5, -1, 1, 5]

points => [0, -5, 5]
```

Case mode => 'step' : Same as in 'continuous' but magnetic field will be swept in stop and go mode. I.e. Magnet approaches field values between start and stop at the interval defined in 'stepwidth'. A measurement is performed, when magnet is idle.

Case mode => 'list' : Array of magnetic field values, with minimum length 1, that are approached in sequence to perform a measurment.

.

rate [float array] (mandatory if not defined duration) array of rates, at which the magnetic field is swept (Tesla / min). Has to be of length 1 or greater (Maximum length: length of points-array). The first value defines the rate to approach the starting point. The following values define the rates to approach the magnetic field values defined by the points-array. If the number of values in the rates-array is less than the length of the points-array, the last defined rate will be used for the remaining sweep sections.

```
points => [-5, -1, 1, 5],
rates => [1, 0.5, 0.2]

rate to approach -5 T (the starting point): 1 T/min
rate to approach -1 T  : 0.5 T/min
rate to approach 1 T  : 0.2 T/min
rate to approach 5 T   : 0.2 T/min (last defined rate)
```

.

duration [float array] (mandatory if not defined rate) can be used instead of 'rate'. Attention: Use only the 'duration' or the 'rate' parameter. Using both will cause an Error!

The first value defines the duration to approach the starting point. The second value defines the duration to approach the magnetic field value defined by the second value of the points-array. ... If the number of values in the duration-array is less than the length of the points-array, last defined duration will be used for the remaining sweep sections.

.

stepwidth [float array] This parameter is relevant only if mode = 'step' has been selected. Stepwidth has to be an array of length '1' or greater. The values define the width for each step within the corresponding sweep sequence. If the length of the defined sweep sequence devided by the stepwidth is not an integer number, the last step will be smaller in order to reach the defined points-value.

```
points = [0, 0.5, 3]
stepwidth = [0.2, 0.5]

==> steps: 0, 0.2, 0.4, 0.5, 1.0, 1.5, 2.0, 2.5, 3
```

.

number_of_points [int array] can be used instead of 'stepwidth'. Attention: Use only the 'number_of_points' or the 'stepwidth' parameter. Using both will cause an Error! This parameter is relevant only if mode = 'step' has been selected. Number_of_points has to be an array of length '1' or greater. The values defines the number of steps within the corresponding sweep sequence.

```
points = [0, 0.5, 3]
number_of_points = [5, 2]

==> steps: 0, 0.1, 0.2, 0.3, 0.4, 0.5, 1.75, 3
```

.

interval [float] (default = 1) interval in seconds for taking measurement points. Only relevant in mode 'continuous'.

.

backsweep [int] (default = 0 | 1 | 2) 0 : no backsweep (default) 1 : a backsweep will be performed 2 : no backsweep performed automatically, but sweep sequence will be reverted every second time the sweep is started (relevant eg. if sweep operates as a slave. This way the sweep sequence is reverted at every second step of the master)

.

id [string] (default = 'Magnet_sweep') Just an ID.

.

filename_extention [string] (default = 'B=') Defines a postfix, that will be appended to the filenames if necessary.

.

delay_before_loop [int] (default = 0) defines the time in seconds to wait after the starting point has been reached.

.

delay_in_loop [int] (default = 0) This parameter is relevant only if mode = 'step' or 'list' has been selected. Defines the time in seconds to wait after the value for the next step has been reached.

.

delay_after_loop [int] (default = 0) Defines the time in seconds to wait after the sweep has been finished. This delay will be executed before an optional backsweep or optional repetitions of the sweep.

.

```
Lab::XPRESS::Sweep::Voltage - voltage sweep
```

1.10.15 .

SYNOPSIS

```
use Lab::XPRESS::hub;
my $hub = new Lab::XPRESS::hub();

my $Yoki = $hub->Instrument('Yokogawa7651',
        {
        connection_type => 'VISA_GPIB',
        gpib_address => 2
        });

my $sweep_voltage = $hub->Sweep('Voltage',
        {
        instrument => $Yoki,
        points => [-1,1],
        rate => [0.1,0.001],
        mode => 'continuous',
        interval => 1,
        backsweep => 1
        });
```

.

DESCRIPTION

Parent: Lab::XPRESS::Sweep::Sweep

The Lab::XPRESS::Sweep::Voltage class implements a module for voltage Sweeps in the Lab::XPRESS::Sweep framework.

.

CONSTRUCTOR

```
my $sweep_voltage = $hub->Sweep('Voltage',
        {
        instrument => $Yoki,
        points => [-1,1],
        rate => [0.1,0.001],
        mode => 'continuous',
        interval => 1,
        backsweep => 1
        });
```

Instantiates a new voltage-sweep.

.

PARAMETERS

instrument [Lab::Instrument] (mandatory) Instrument, conducting the sweep. Must be of type Lab:Instrument. Allowed instruments: Lab::Instrument::Yokogawa7651

.

mode [string] (default = 'continuous' | 'step' | 'list') continuous: perform a continuous voltage sweep. Measurements will be performed constantly at the time-interval defined in interval.

step: measurements will be performed at discrete values of the applied voltage between start and end points defined in parameter points, seperated by voltage steps defined in parameter stepwidth

list: measurements will be performed at a list voltage values defined in parameter points

.

points [float array] (mandatory) array of voltage values (in volts) that defines the characteristic points of the sweep. First value is appraoched before measurement begins.

Case mode => 'continuous' : List of at least 2 values, that define start and end point of the sweep or a sequence of consecutive sweep-sections (e.g. if changing the sweep-rate for different sections or reversing the sweep direction). points => [-5, 5] # Start: -5 / Stop: 5

```
points => [-5, -1, 1, 5]

points => [0, -5, 5]
```

Case mode => 'step' : Same as in 'continuous' but voltage will be swept in stop and go mode. I.e. voltage source approaches values between start and stop at the interval defined in 'stepwidth'. A measurement is performed, when voltage source is idle.

Case mode => 'list' : Array of voltages, with minimum length 1, that are approached in sequence to perform a measurment.

.

rate [float array] (mandatory if not defined duration) array of rates, at which the voltage is swept (V / sec). Has to be of length 1 or greater (Maximum length: length of points-array). The first value defines the rate to approach the starting point. The following values define the rates to approach the voltages defined by the points-array. If the number of values in the rates-array is less than the length of the points-array, the last defined rate will be used for the remaining sweep sections.

```
points => [-5, -1, 1, 5],
rates => [1, 0.005, 0.02]
```

```
rate to approach -5 V (the starting point): 1 V/sec
rate to approach -1 V  : 0.005 V/sec
rate to approach 1 V   : 0.02 V/sec
rate to approach 5 V   : 0.02 V/sec (last defined rate)
```

.

duration [float array] (mandatory if not defined rate) can be used instead of 'rate'. Attention: Use only the 'duration' or the 'rate' parameter. Using both will cause an Error!

The first value defines the duration to approach the starting point. The second value defines the duration to approach the voltage value defined by the second value of the points-array. ... If the number of values in the duration-array is less than the length of the points-array, last defined duration will be used for the remaining sweep sections.

.

stepwidth [float array] This parameter is relevant only if mode = 'step' has been selected. Stepwidth has to be an array of length '1' or greater. The values define the width for each step within the corresponding sweep sequence. If the length of the defined sweep sequence devided by the stepwidth is not an integer number, the last step will be smaller in order to reach the defined points-value.

```
points = [0, 0.5, 3]
stepwidth = [0.2, 0.5]

==> steps: 0, 0.2, 0.4, 0.5, 1.0, 1.5, 2.0, 2.5, 3
```

.

number_of_points [int array] can be used instead of 'stepwidth'. Attention: Use only the 'number_of_points' or the 'stepwidth' parameter. Using both will cause an Error! This parameter is relevant only if mode = 'step' has been selected. Number_of_points has to be an array of length '1' or greater. The values defines the number of steps within the corresponding sweep sequence.

```
points = [0, 0.5, 3]
number_of_points = [5, 2]

==> steps: 0, 0.1, 0.2, 0.3, 0.4, 0.5, 1.75, 3
```

.

interval [float] (default = 1) interval in seconds for taking measurement points. Only relevant in mode 'continuous'.

.

backsweep [int] (default = 0 | 1 | 2) 0 : no backsweep (default) 1 : a backsweep will be performed 2 : no backsweep performed automatically, but sweep sequence will be reverted every second time the sweep is started (relevant eg. if sweep operates as a slave. This way the sweep sequence is reverted at every second step of the master)

.

jump [int] (default = 0 | 1) can be used to switch off the sweeping between adjacent points in step or list mode.

0 : a sweep is performed between adjacent steps (default) 1 : the voltage is set without sweeping, given that gateprotect does not trigger a sweep.

.

id [string] (default = 'Voltage_sweep') Just an ID.

.

filename_extention [string] (default = 'V=') Defines a postfix, that will be appended to the filenames if necessary.

.

delay_before_loop [int] (default = 0) defines the time in seconds to wait after the starting point has been reached.

.

delay_in_loop [int] (default = 0) This parameter is relevant only if mode = 'step' or 'list' has been selected. Defines the time in seconds to wait after the value for the next step has been reached.

.

delay_after_loop [int] (default = 0) Defines the time in seconds to wait after the sweep has been finished. This delay will be executed before an optional backsweep or optional repetitions of the sweep.

.

```
Lab::XPRESS::Sweep::Time - simple time controlled repeater
```

1.10.16 .

SYNOPSIS

```
use Lab::XPRESS::hub;
my $hub = new Lab::XPRESS::hub();

my $repeater = $hub->Sweep('Time',
        {
        duration => 5
        });
```

.

DESCRIPTION

Parent: Lab::XPRESS::Sweep::Sweep

The Lab::XPRESS::Sweep::Time class implements a simple time controlled repeater module in the Lab::XPRESS::Sweep framework.

.

CONSTRUCTOR

```
my $repeater = $hub->Sweep('Time',
        {
        repetitions => 5
        });
```

Instantiates a new Repeater.

.

PARAMETERS

duration [int] (default = 1) duration for the time controlled repeater. Default value is 1, negative values indicate a infinit number of repetitions.

.

interval [int] (default = 1) interval in seconds for taking measurement points.

.

id [string] (default = 'Repeater') Just an ID.

.

delay_before_loop [int] (default = 0) defines the time in seconds to wait after the starting point has been reached.

.

delay_after_loop [int] (default = 0) Defines the time in seconds to wait after the sweep has been finished. This delay will be executed before an optional backsweep or optional repetitions of the sweep.

.

```
Lab::XPRESS::Sweep::Motor - stepper motor sweep
```

1.10.17 .

SYNOPSIS

```
use Lab::XPRESS::hub;
my $hub = new Lab::XPRESS::hub();

my $stepper = $hub->Instrument('PDPD11042',
        {
        connection_type => 'VISA_RS232',
        gpib_address => 2
        });

my $sweep_motor = $hub->Sweep('Motor',
        {
        instrument => $stepper,
        points => [-10,10],
        rate => [1.98,1],
        mode => 'continuous',
        interval => 1,
        backsweep => 1
        });
```

.

DESCRIPTION

Parent: Lab::XPRESS::Sweep::Sweep

The Lab::XPRESS::Sweep::Motor class implements a module for stepper motor sweeps in the Lab::XPRESS::Sweep framework.

.

CONSTRUCTOR

```
my $sweep_motor = $hub->Sweep('Motor',
        {
        instrument => $stepper,
        points => [-10,10],
        rate => [1.98,1],
        mode => 'continuous',
        interval => 1,
        backsweep => 1
        });
```

Instantiates a new stepper motor sweep

.

SWEEP PARAMETERS

instrument [Lab::Instrument] (mandatory) Instrument, conducting the sweep. Must be of type Lab:Instrument. Allowed instruments: Lab::Instrument::PD11042, Lab::Instrument::ProSte

.

mode [string] (default = 'continuous' | 'step' | 'list') continuous: perform a continuous stepper motor sweep. Measurements will be performed constantly at the time-interval defined in interval.

step: measurements will be performed at discrete values between start and end points defined in parameter points, seperated by a step defined in parameter stepwidth

list: measurements will be performed at a list of values defined in parameter points

.

points [float array] (mandatory) array of values (in deg) that defines the characteristic points of the sweep. First value is appraoched before measurement begins.

Case mode => 'continuous' : List of at least 2 values, that define start and end point of the sweep or a sequence of consecutive sweep-sections (e.g. if changing the sweep-rate for different sections or reversing the sweep direction). points => [0, 180] # Start: 0 / Stop: 180

```
points => [0, 90, 180, 360]

points => [0, -90, 90]
```

Case mode => 'step' : Same as in 'continuous' but stepper motor will be swept in stop and go mode. I.e. stepper motor approaches values between start and stop at the interval defined in 'stepwidth'. A measurement is performed, when the motor is idle.

Case mode => 'list' : Array of values, with minimum length 1, that are approached in sequence to perform a measurment.

.

rate [float array] (mandatory if not defined duration) array of rates, at which the stepper motor is swept (deg / min). Has to be of length 1 or greater (Maximum length: length of points-array). The first value defines the rate to approach the starting point. The following values define the rates to approach the values defined by the points-array. If the number of values in the rates-array is less than the length of the points-array, the last defined rate will be used for the remaining sweep sections.

```
points => [-90, 0, 90, 180],
rates => [1, 0.5, 0.2]

rate to approach -90 deg (the starting point): 1 deg/min
rate to approach 0 deg  : 0.5 deg/min
rate to approach 90 deg  : 0.2 deg/min
rate to approach 180 deg   : 0.2 deg/min (last defined rate)
```

.

duration [float array] (mandatory if not defined rate) can be used instead of 'rate'. Attention: Use only the 'duration' or the 'rate' parameter. Using both will cause an Error!

The first value defines the duration to approach the starting point. The second value defines the duration to approach the value defined by the second value of the points-array. ... If the number of values in the duration-array is less than the length of the points-array, last defined duration will be used for the remaining sweep sections.

.

stepwidth [float array] This parameter is relevant only if mode = 'step' has been selected. Stepwidth has to be an array of length '1' or greater. The values define the width for each step within the corresponding sweep sequence. If the length of the defined sweep sequence devided by the stepwidth is not an integer number, the last step will be smaller in order to reach the defined points-value.

```
points = [0, 90, 180]
stepwidth = [10, 25]

==> steps: 0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 115, 140, 165,
    180
```

.

number_of_points [int array] can be used instead of 'stepwidth'. Attention: Use only the 'number_of_points' or the 'stepwidth' parameter. Using both will cause an Error! This parameter is relevant only if mode = 'step' has been selected. Number_of_points has to be an array of length '1' or greater. The values defines the number of steps within the corresponding sweep sequence.

```
points = [0, 90, 180]
number_of_points = [5, 2]

==> steps: 0, 18, 36, 54, 72, 90, 135, 180
```

.

interval [float] (default = 1) interval in seconds for taking measurement points. Only relevant in mode 'continuous'.

.

backsweep [int] (default = 0 | 1 | 2) 0 : no backsweep (default) 1 : a backsweep will be performed 2 : no backsweep performed automatically, but sweep sequence will be reverted every second time the sweep is started (relevant eg. if sweep operates as a slave. This way the sweep sequence is reverted at every second step of the master)

.

id [string] (default = 'Motor_sweep') Just an ID.

.

filename_extention [string] (default = 'PHI=') Defines a postfix, that will be appended to the filenames if necessary.

.

delay_before_loop [int] (default = 0) defines the time in seconds to wait after the starting point has been reached.

.

delay_in_loop [int] (default = 0) This parameter is relevant only if mode = 'step' or 'list' has been selected. Defines the time in seconds to wait after the value for the next step has been reached.

.

delay_after_loop [int] (default = 0) Defines the time in seconds to wait after the sweep has been finished. This delay will be executed before an optional backsweep or optional repetitions of the sweep.

.

```
Lab::XPRESS::Sweep::Repeater - simple repeater
```

1.10.18 .

SYNOPSIS

```
use Lab::XPRESS::hub;
my $hub = new Lab::XPRESS::hub();

my $repeater = $hub->Sweep('Repeater',
        {
        repetitions => 5
        });
```

.

DESCRIPTION

Parent: Lab::XPRESS::Sweep::Sweep

The Lab::XPRESS::Sweep::Repeater class implements a simple repeater module in the Lab::XPRESS::Sweep framework.

.

CONSTRUCTOR

```
my $repeater = $hub->Sweep('Repeater',
        {
        repetitions => 5
        });
```

Instantiates a new Repeater.

.

PARAMETERS

repetitions [int] (default = 1) number of repetitions. default value is 1, negative values indicate a infinit number of repetitions.

.

id [string] (default = 'Repeater') Just an ID.

.

filename_extention [string] (default = '#=') Defines a postfix, that will be appended to the filenames if necessary.

.

delay_before_loop [int] (default = 0) defines the time in seconds to wait after the starting point has been reached.

.

delay_in_loop [int] (default = 0) This parameter is relevant only if mode = 'step' or 'list' has been selected. Defines the time in seconds to wait after the value for the next step has been reached.

.

delay_after_loop [int] (default = 0) Defines the time in seconds to wait after the sweep has been finished. This delay will be executed before an optional backsweep or optional repetitions of the sweep.

.

```
Lab::XPRESS::Sweep::Temperature - temperature sweep
```

1.10.19 .

SYNOPSIS

```
use Lab::XPRESS::hub;
my $hub = new Lab::XPRESS::hub();

my $tsensor = $hub->Instrument('ITC',
        {
        connection_type => 'VISA_RS232',
        gpib_address => 2
        });

my $sweep_temperature = $hub->Sweep('Temperature',
        {
        instrument => $tsensor,
        points => [90,4],
        mode => 'list'
        });
```

.

DESCRIPTION

Parent: Lab::XPRESS::Sweep::Sweep

The Lab::XPRESS::Sweep::Temperature class implements a module for temperature sweeps in the Lab::XPRESS::Sweep framework.

.

CONSTRUCTOR

```
my $sweep_temperature = $hub->Sweep('Temperature',
        {
        instrument => $tsensor,
        points => [90,4],
        mode => 'list'
        });
```

Instantiates a new temperature sweep

.

PARAMETERS

instrument [Lab::Instrument] (mandatory) Instrument, conducting the sweep. Must be of type Lab:Instrument. Supported instruments: Lab::Instrument::ITC

.

mode [string] (default = 'continuous' | 'step' | 'list') continuous: perform a continuous temperature sweep. After the starting temperature has been stabalized by the temperature controller, the heater will be switched off in order to cool down to the final value. Measurements will be performed constantly at the time-interval defined in interval.

step: measurements will be performed at discrete values between start and end points defined in parameter points, seperated by a step defined in parameter stepwidth

list: measurements will be performed at a list of values defined in parameter points

.

points [float array] (mandatory) array of values (in deg) that defines the characteristic points of the sweep. First value is appraoched before measurement begins.

Case mode => 'continuous' : List of exactly 2 values, that define start and end point of the sweep. The starting point has to be higher value than the endpont. points => [180, 4] # Start: 180 K / Stop: 4 K

Case mode => 'step' : Same as in 'continuous' but the temperature controller will stabalize the temperature at the defined setpoints. A measurement is performed, when the motor is idle.

Case mode => 'list' : Array of values, with minimum length 1, that are approached in sequence to perform a measurment.

.

stepwidth [float array] This parameter is relevant only if mode = 'step' has been selected. Stepwidth has to be an array of length '1' or greater. The values define the width for each step within the corresponding sweep sequence. If the length of the defined sweep sequence devided by the stepwidth is not an integer number, the last step will be smaller in order to reach the defined points-value.

```
points = [0, 90, 180]
stepwidth = [10, 25]

==> steps: 0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 115, 140, 165,
    180
```

.

number_of_points [int array] can be used instead of 'stepwidth'. Attention: Use only the 'number_of_points' or the 'stepwidth' parameter. Using both will cause an Error! This parameter is relevant only if mode = 'step' has been selected. Number_of_points has to be an array of length '1' or greater. The values defines the number of steps within the corresponding sweep sequence.

```
points = [0, 90, 180]
number_of_points = [5, 2]
```

```
==> steps: 0, 18, 36, 54, 72, 90, 135, 180
```

.

interval [float] (default = 1) interval in seconds for taking measurement points. Only relevant in mode 'continuous'.

.

id [string] (default = 'Temperature_sweep') Just an ID.

.

filename_extention [string] (default = 'T=') Defines a postfix, that will be appended to the filenames if necessary.

.

delay_before_loop [int] (default = 0) defines the time in seconds to wait after the starting point has been reached.

.

delay_in_loop [int] (default = 0) This parameter is relevant only if mode = 'step' or 'list' has been selected. Defines the time in seconds to wait after the value for the next step has been reached.

.

delay_after_loop [int] (default = 0) Defines the time in seconds to wait after the sweep has been finished. This delay will be executed before an optional backsweep or optional repetitions of the sweep.

.

1.11 Instrument control classes

1.11.1 Lab::Instrument

Instrument base class

SYNOPSIS

Lab::Instrument is meant to be used as a base class for inheriting instruments. For very simple applications it can also be used directly, like

```
$generic_instrument = new Lab::Instrument ( connection_type =>
    VISA_GPIB, gpib_address => 14 );
my $idn = $generic_instrument->query('*IDN?');
```

Every inheriting class constructor should start as follows:

```
sub new {
  my $proto = shift;
  my $class = ref($proto) || $proto;
  my $self = $class->SUPER::new(@_);
  $self->${\(__PACKAGE__.'::_construct')}(__PACKAGE__); # check for
      supported connections, initialize fields etc.
  ...
}
```

Beware that only the first set of parameters specific to an individual GPIB board or any other bus hardware gets used. Settings for EOI assertion for example.

If you know what you're doing or you have an exotic scenario you can use the connection parameter "ignore_twins => 1" to force the creation of a new bus object, but this is discouraged - it will kill bus management and you might run into hardware/resource sharing issues.

DESCRIPTION

`Lab::Instrument` is the base class for Instruments. It doesn't do much by itself, but is meant to be inherited in specific instrument drivers. It provides general `read`, `write` and `query` methods and basic connection handling (internally, `_set_connection`, `_check_connection`).

CONSTRUCTOR

new This blesses $self (don't do it yourself in an inheriting class!), initializes the basic "fields" to be accessed via AUTOLOAD and puts the configuration hash in $self->config to be accessed in methods and inherited classes.

Arguments: just the configuration hash (or even-sized list) passed along from a child class constructor.

METHODS

write

```
$instrument->write($command <, {optional hashref/hash}> );
```

Sends the command `$command` to the instrument. An option hash can be supplied as second or also as only argument. Generally, all options are passed to the connection/bus, so additional named options may be supported based on the connection and bus and can be passed as a hashref or hash. See *Lab::Connection*.

Optional named parameters for hash:

```
error_check => 1/0
```

Invoke $instrument->check_errors after write. Defaults to off.

read

```
$result=$instrument->read({ read_length => <max length>, brutal =>
    <1/0>);
```

Reads a result of `ReadLength` from the instrument and returns it. Returns an exception on error.

If the parameter `brutal` is set, a timeout in the connection will not result in an Exception thrown, but will return the data obtained until the timeout without further comment. Be aware that this data is also contained in the the timeout exception object (see `Lab::Exception`).

Generally, all options are passed to the connection/bus, so additional named options may be supported based on the connection and bus and can be passed as a hashref or hash. See *Lab::Connection*.

query

```
$result=$instrument->query({ command => $command,
                                 wait_query => $wait_query,
                             read_length => $read_length);
```

Sends the command `$command` to the instrument and reads a result from the instrument and returns it. The length of the read buffer is set to `read_length` or to the default set in the connection.

Waits for `wait_query` microseconds before trying to read the answer.

Generally, all options are passed to the connection/bus, so additional named options may be supported based on the connection and bus and can be passed as a hashref or hash. See *Lab::Connection*.

get_error

```
        ($errcode, $errmsg) = $instrument->get_error();
```

Method stub to be overwritten. Implementations read one error (and message, if available) from the device.

get_status

```
$status = $instrument->get_status();
if( $instrument->get_status('ERROR') ) {...}
```

Method stub to be overwritten. This returns the status reported by the device (e.g. the status byte retrieved via serial poll from GPIB devices). When implementing, use only information which can be retrieved very fast from the device, as this may be used often.

Without parameters, has to return a hashref with named status bits, e.g.

```
$status => {
        ERROR => 1,
        DATA => 0,
        READY => 1
}
```

If present, the first argument is interpreted as a key and the corresponding value of the hash above is returned directly.

The 'ERROR'-key has to be implemented in every device driver!

check_errors

```
$instrument->check_errors($last_command);

# try
eval { $instrument->check_errors($last_command) };
# catch
if ( my $e = Exception::Class->caught('Lab::Exception::
    DeviceError')) {
        warn "Errors from device!";
        @errors = $e->error_list();
        @devtype = $e->device_class();
        $command = $e->command();
}
```

Uses get_error() to check the device for occured errors. Reads all present errors and throws a Lab::Exception::DeviceError. The list of errors, the device class and the last issued command(s) (if the script provided them) are enclosed.

_check_args

```
my ($arg_1, $arg_2, ... ) = $instrument->_check_args(\@args,
    @arg_names );

This methode is expected to be used to deal with the different
    possibilities a user can pass arguments when calling an
    instruments methode.
@args are the users arguments. The expected arguments of a
    specific methode may be $arg_1 and $arg_2.
Using the old style calling a methode, you have to pass the two
    arguments in the right order.
```

```
Using the new style, you can pass the arguments as a HASH using
    the arguments' names @arg_names. You don't have to take care
     of the right order in this case.
Furthermore the methode triggers a waring if it finds unknown
    parameter in the arguments hash ( this is to cathch typos in
     the script ).
```

1.11.2 Multimeters

Lab::Instrument::Multimeter

Generic digital multimeter interface

DESCRIPTION The Lab::Instrument::Multmeter class implements a generic interface to digital all-purpose multimeters. It is intended to be inherited by other classes, not to be called directly, and provides a set of generic functions. The class

CONSTRUCTOR

```
my $hp=new(\%options);
```

METHODS

get_value

```
$value=$hp->get_value();
```

Read out the current measurement value, for whatever type of measurement the multimeter is currently configured.

id

```
$id=$hp->id();
```

Returns the instruments ID string.

display_on

```
$hp->display_on();
```

Turn the front-panel display on.

display_off

```
$hp->display_off();
```

Turn the front-panel display off.

display_text

```
$hp->display_text($text);
```

Display a message on the front panel.

display_clear

```
$hp->display_clear();
```

Clear the message displayed on the front panel.

Lab::Instrument::HP34401A

HP/Agilent 34401A digital multimeter

SYNOPSIS

```
use Lab::Instrument::HP34401A;

my $Agi = new Lab::Instrument::HP34401A({
  connection => new Lab::Connection::GPIB(
              gpib_board => 0,
              gpib_address => 14,
      ),
}
```

DESCRIPTION The Lab::Instrument::HP34401A class implements an interface to the 34401A digital multimeter by Agilent (formerly HP). This module can also be used to address the newer 34410A and 34411A multimeters, but doesn't include new functions. Use the *Lab::Instrument::HP34411A* class for full functionality (not ported yet).

CONSTRUCTOR

```
my $Agi=new(\%options);
```

METHODS

fetch

```
$hp->fetch();
```

Fetches the instrument buffer. Returns an array of values.

autozero

```
$hp->autozero($setting);
```

$setting can be 1/'ON', 0/'OFF' or 'ONCE'.

When set to "ON", the device takes a zero reading after every measurement. "ONCE" perform one zero reading and disables the automatic zero reading. "OFF" does... you get it.

configure_voltage_dc

```
$hp->configure_voltage_dc($range, $integration_time, $resolution);
```

Configures all the details of the device's DC voltage measurement function.

$range is a positive numeric value (the largest expected value to be measured) or one of 'MIN', 'MAX', 'AUTO'. It specifies the largest value to be measured. You can set any value, but the HP/Agilent 34401A effectively uses one of the values 0.1, 1, 10, 100 and 1000V.

$integration_time is the integration time in seconds or MIN MAX DEF. This implicitly sets the provided resolution.

$resolution sets the resolution of the measurment. If set, $integration_time is overwritten.

configure_voltage_dc_trigger

```
$hp->configure_voltage_dc_trigger($range, $integration_time,
    $count, $delay, $resolution)
```

Configures the device for successive triggered reading events. Does not initiate the trigger facility. Reading can then be performed calling triggered_read(). The first three parameters are just passed to configure_voltage_dc.

$count is an integer for the number of successive readings that follow one single trigger event.

$delay is the delay in seconds between these readings.

triggered_read

```
@data = $hp->triggered_read();
```

Sends a trigger pulse and fetches the values from the instrument buffer once the reading is finished.

read_trig() Sends a read trigger to the device. It does not initialize the trigger facility.

init() Initializes the trigger facility. The device is then in the state "waiting for trigger".

get_value

```
$data = hp->get_value();
```

Inherited from *Lab::Instrument::Multimeter*. Performs a single reading in the current configuration.

get_voltage_dc

```
$datum=$Agi->get_voltage_dc($range,$resolution);
```

Preset and make a dc voltage measurement with the specified range and resolution.

get_voltage_ac

```
$datum=$Agi->get_voltage_ac($range,$resolution);
```

Preset and make a ac voltage measurement with the specified range and resolution.

get_current_dc

```
$datum = $hp->get_current_dc($range,$resolution);
```

Preset and make a dc current measurement with the specified range and resolution.

get_current_ac

```
$datum = $hp->get_current_ac($range,$resolution);
```

Preset and make a ac current measurement with the specified range and resolution.

get_resistance

```
$resistance=$Agi->get_resistance($range,$resolution);
```

Preset and measure resistance with specified range and resolution.

get_4wresistance

```
$resistance=$Agi->get_4wresistance($range,$resolution);
```

Preset and measure the four way resistance with specified range and resolution.

get_status() Returns a status string from the device.

get_error() Returns the error string from the device.

pl_freq Parameter: pl_freq

```
$hp->pl_freq($new_freq);
$npl_freq = $hp->pl_freq();
```

Get/set the power line frequency at your location (50 Hz for most countries, which is the default). This is the basis of the integration time setting (which is internally specified as a count of power line cycles, or PLCs). The integration time will be set incorrectly if this parameter is set incorrectly.

set_display_text

```
$Agi->display_text($text);
print $Agi->display_text();
```

Display a message on the front panel. The multimeter will display up to 12 characters in a message; any additional characters are truncated. Without parameter the displayed message is returned. Inherited from *Lab::Instrument::Multimeter*

set_display_state

```
$Agi->set_display_state($state);
```

Turn the front-panel display on ($state = "ON") or off ($state = "OFF").

$range

Range is given in terms of volts and can be `[0.1|1|10|100|1000|MIN|MAX|DEF]`. `DEF` is default.

$resolution

Resolution is given in terms of `$range` or `[MIN|MAX|DEF]`. `$resolution=0.0001` means 4 1/2 digits for example. The best resolution is 100nV: `$range=0.1`; `$resolution=0.000001`.

get_voltage_ac

```
$datum=$Agi->get_voltage_ac($range,$resolution);
```

Preset and make an ac voltage measurement with the specified range and resolution. For ac measurements, resolution is actually fixed at 6 1/2 digits. The resolution parameter only affects the front-panel display.

get_current_dc

```
$datum=$Agi->get_current_dc($range,$resolution);
```

Preset and make a dc current measurement with the specified range and resolution.

get_current_ac

```
$datum=$Agi->get_current_ac($range,$resolution);
```

Preset and make an ac current measurement with the specified range and resolution. For ac measurements, resolution is actually fixed at 6 1/2 digits. The resolution parameter only affects the front-panel display.

configure_voltage_dc_trigger

```
$device->trigger_mode($intt, $range, $count, $delay, $resolution
    )
```

Configure the multimeter for a triggered reading.

$intt

The integration time in seconds. You can also set "MIN" or "MAX". This value is overwritten if the resolution is specified.

$range

The range for the measurment.

$count

The number of measurements which are performed after one single trigger impulse.

$delay

The delay between the `$count` measurements (the integration time is not included).

$resolution

The resolution for the measurement. If given, this overwrites the `$intt` parameter.

trigger_read

```
$data = $device->trigger_read()
```

Sends a trigger signal and fetches the value(s) from the multimeter.

trigger

```
$device->trigger()
```

Sends a trigger signal to the device.

fetch

```
$data = $device->fetch()
```

Fetches the data which is currently in the output buffer of the device.

scroll_message

```
$Agi->scroll_message($message);
```

Scrolls the message `$message` on the display of the HP.

beep

```
$Agi->beep();
```

Issue a single beep immediately.

get_error

```
($err_num,$err_msg)=$Agi->get_error();
```

Query the multimeter's error queue. Up to 20 errors can be stored in the queue. Errors are retrieved in first-in-first out (FIFO) order.

reset

```
$Agi->reset();
```

Reset the multimeter to its power-on configuration.

Lab::Instrument::HP34420A

HP/Agilent 34420A digital multimeter

SYNOPSIS

```
use Lab::Instrument::HP34420A;

my $Agi = new Lab::Instrument::HP34420A({
  connection => new Lab::Connection::GPIB(
                gpib_board => 0,
                gpib_address => 14,
        ),
}
```

DESCRIPTION The Lab::Instrument::HP34420A class implements an interface to the 34420A digital multimeter by Agilent (formerly HP). This module is in big parts equal to the 34410A and 34411A multimeter drivers.

CONSTRUCTOR

```
my $Agi=new(\%options);
```

METHODS

fetch

```
$hp->fetch();
```

Fetches the instrument buffer. Returns an array of values.

autozero

```
$hp->autozero($setting);
```

$setting can be 1/'ON', 0/'OFF' or 'ONCE'.

When set to "ON", the device takes a zero reading after every measurement. "ONCE" perform one zero reading and disables the automatic zero reading. "OFF" does... you get it.

configure_voltage_dc

```
$hp->configure_voltage_dc($range, $integration_time);
```

Configures all the details of the device's DC voltage measurement function.

$range is a positive numeric value (the largest expected value to be measured) or one of 'MIN', 'MAX', 'AUTO'. It specifies the largest value to be measured. You can set any value, but the HP/Agilent 34401A effectively uses one of the values 0.1, 1, 10, 100 and 1000V.

$integration_time is the integration time in seconds. This implicitly sets the provided resolution.

pl_freq Parameter: pl_freq

```
$hp->pl_freq($new_freq);
$npl_freq = $hp->pl_freq();
```

Get/set the power line frequency at your location (50 Hz for most countries, which is the default). This is the basis of the integration time setting (which is internally specified as a count of power line cycles, or PLCs). The integration time will be set incorrectly if this parameter is set incorrectly.

set_display_text

```
$Agi->display_text($text);
print $Agi->display_text();
```

Display a message on the front panel. The multimeter will display up to 12 characters in a message; any additional characters are truncated. Without parameter the displayed message is returned. Inherited from *Lab::Instrument::Multimeter*

set_display_state

```
$Agi->set_display_state($state);
```

Turn the front-panel display on ($state = "ON") or off ($state = "OFF").

get_resistance

```
$resistance=$Agi->get_resistance($range,$resolution);
```

Preset and measure resistance with specified range and resolution.

get_voltage_dc

```
$datum=$Agi->get_voltage_dc($range,$resolution);
```

Preset and make a dc voltage measurement with the specified range and resolution.

$range

Range is given in terms of volts and can be `[0.1|1|10|100|1000|MIN|MAX|DEF]`. `DEF` is default.

$resolution

Resolution is given in terms of `$range` or `[MIN|MAX|DEF]`. `$resolution=0.0001` means 4 1/2 digits for example. The best resolution is 100nV: `$range=0.1`; `$resolution=0.000001`.

get_voltage_ac

```
$datum=$Agi->get_voltage_ac($range,$resolution);
```

Preset and make an ac voltage measurement with the specified range and resolution. For ac measurements, resolution is actually fixed at 6 1/2 digits. The resolution parameter only affects the front-panel display.

get_current_dc

```
$datum=$Agi->get_current_dc($range,$resolution);
```

Preset and make a dc current measurement with the specified range and resolution.

get_current_ac

```
$datum=$Agi->get_current_ac($range,$resolution);
```

Preset and make an ac current measurement with the specified range and resolution. For ac measurements, resolution is actually fixed at 6 1/2 digits. The resolution parameter only affects the front-panel display.

configure_voltage_dc_trigger

```
$device->configure_voltage_dc_trigger($intt, $range, $count,
    $delay, $resolution)
```

Configure the multimeter for a triggered reading.

$intt

The integration time in seconds. You can also set "MIN" or "MAX". This value is overwritten if the resolution is specified.

$range

The range for the measurment.

$count

The number of measurements which are performed after one single trigger impulse.

$delay

The delay between the `$count` measurements (the integration time is not included).

$resolution

The resolution for the measurement. If given, this overwrites the `$intt` parameter.

trigger_read

```
$data = $device->trigger_read()
```

Sends a trigger signal and fetches the value(s) from the multimeter.

trigger

```
$device->trigger()
```

Sends a trigger signal to the device.

fetch

```
$data = $device->fetch()
```

Fetches the data which is currently in the output buffer of the device.

beep

```
$Agi->beep();
```

Issue a single beep immediately.

get_error

```
($err_num,$err_msg)=$Agi->get_error();
```

Query the multimeter's error queue. Up to 20 errors can be stored in the queue. Errors are retrieved in first-in-first out (FIFO) order.

reset

```
$Agi->reset();
```

Reset the multimeter to its power-on configuration.

Lab::Instrument::HP3458A

Agilent 3458A Multimeter

SYNOPSIS

```
use Lab::Instrument::HP3458A;

my $dmm=new Lab::Instrument::HP3458A({
    gpib_board   => 0,
    gpib_address => 11,
});
print $dmm->get_voltage_dc();
```

DESCRIPTION The Lab::Instrument::HP3458A class implements an interface to the Agilent / HP 3458A digital multimeter.

CONSTRUCTOR

```
my $hp=new(%parameters);
```

METHODS

pl_freq Parameter: pl_freq

```
$hp->pl_freq($new_freq);
$npl_freq = $hp->pl_freq();
```

Get/set the power line frequency at your location (50 Hz for most countries, which is the default). This is the basis of the integration time setting (which is internally specified as a count of power line cycles, or PLCs). The integration time will be set incorrectly if this parameter is set incorrectly.

get_voltage_dc

```
$voltage=$hp->get_voltage_dc();
```

Make a dc voltage measurement. This also enables autoranging. For finer control, use configure_voltage_dc() and triggered_read.
_head2 triggered_read

```
@values = $hp->triggered_read();
$value = $hp->triggered_read();
```

Trigger and read value(s) using the current device setup. This expects and digests a list of values in ASCII format, as set up by configure_voltage_dc().

triggered_read_raw

```
$result = $hp->triggered_read_raw( read_until_length => $length );
```

Trigger and read using the current device setup. This won't do any parsing and just return the answer from the device. If $read_until_length (integer) is specified, it will try to continuously read until it has gathered this amount of bytes.

configure_voltage_dc

```
$hp->configure_voltage_dc($range, $integration_time);
```

Configure range and integration time for the following DCV measurements.

$range is a voltage or one of "AUTO", "MIN" or "MAX". $integration_time is given in seconds or one of "DEFAULT", "MIN" or "MAX".

configure_voltage_dc_trigger

```
$hp->configure_voltage_dc_trigger($range, $integration_time,
  $count, $delay);
```

Configures range, integration time, sample count and delay (between samples) for triggered readings.

$range, $integration_time: see configure_voltage_dc(). $count is the sample count per trigger (integer). $delay is the delay between the samples in seconds.

configure_voltage_dc_trigger_highspeed

```
$hp->configure_voltage_dc_trigger_highspeed($range,
  $integration_time, $count, $delay);
```

Same as configure_voltage_dc_trigger, but configures the device for maximum measurement speed. Values are transferred in SINT format and can be fetched and decoded using triggered_read_raw() and decode_SINT(). This mode allows measurements of up to about 100 kSamples/second.

$range: see configure_voltage_dc(). $integration_time: integration time in seconds. The default is 1.4e-6. $count is the sample count per trigger (integer). $delay is the delay between the samples in seconds.

set_display_state

```
$hp->set_display_state($state);
```

Turn the front-panel display on/off. $state can be each of '1', '0', 'on', 'off'.

set_display_text

```
$hp->set_display_text($text);
```

Display a message on the front panel. The multimeter will display up to 12 characters in a message; any additional characters are truncated.

display_clear

```
$hp->display_clear();
```

Clear the message displayed on the front panel.

beep

```
$hp->beep();
```

Issue a single beep immediately.

get_error

```
($err_num,$err_msg)=$hp->get_error();
```

Query the multimeter's error queue. Up to 20 errors can be stored in the queue. Errors are retrieved in first-in-first out (FIFO) order.

check_errors

```
$instrument->check_errors($last_command);

# try
eval { $instrument->check_errors($last_command) };
# catch
if ( my $e = Exception::Class->caught('Lab::Exception::DeviceError')
    ) {
    warn "Errors from device!";
    @errors = $e->error_list();
    @devtype = $e->device_class();
    $command = $e->command();
} else {
    $e = Exception::Class->caught();
    ref $e ? $e->rethrow; die $e;
}
```

Uses get_error() to check the device for occured errors. Reads all present error and throws a Lab::Exception::DeviceError. The list of errors, the device class and the last issued command(s) (if the script provided them) are enclosed.

set_nplc

```
$hp->set_nplc($number);
```

Sets the integration time in units of power line cycles.

reset

```
$hp->reset();
```

Reset the multimeter to its power-on configuration. Same as preset('NORM').

preset

```
$hp->preset($config);
```

$config can be any of the following settings:

```
'FAST'   / 0
'NORM'   / 1
'DIG'    / 2
```

Choose one of several configuration presets.

selftest

```
$hp->selftest();
```

Starts the internal self-test routine.

autocalibration

```
$hp->autocalibration($mode);
```

Starts the internal autocalibration. Warning... this procedure takes 11 minutes with the 'ALL' mode!

$mode can be each of

```
'ALL'   / 0
'DCV'   / 1
'AC'    / 2
'OHMS'  / 4
```

decode_SINT

```
@values = $hp->decode_SINT( $SINT_data, <$iscale> );
```

Takes a data blob with SINT values and decodes them into a numeric list. The used $iscale parameter is read from the device by default if omitted. Make sure the device still has the same settings as used to obtain $SINT_data, or iscale will be off which leads to invalid data decoding.

1.11.3 Voltage sources

Lab::Instrument::Source

Base class for voltage source instruments

SYNOPSIS

DESCRIPTION This class implements a general voltage source, if necessary with several channels. It is meant to be inherited by instrument classes that implement real voltage sources (e.g. the *Lab::Instrument::Yokogawa7651* class).

The class provides a unified user interface for those voltage sources to support the exchangeability of instruments.

Additionally, this class provides a safety mechanism called `gate_protect` to protect delicate samples. It includes automatic limitations of sweep rates, voltage step sizes, minimal and maximal voltages.

There's no direct user application of this class.

CONSTRUCTOR

```
$self=new Lab::Instrument::Source(\%config);
```

This constructor will only be used by instrument drivers that inherit this class, not by the user. It accepts an additional configuration hash as parameter 'default_device_settings'. The first hash contains the parameters used by default for this device and its subchannels, if any. The second hash can be used to override options for this instance while still using the defaults for derived objects. If \%config is missing, \%default_config is used.

The instrument driver (e.g. *Lab::Instrument::Yokogawa7651*) has e.g. a constructor like this:

```
$yoko=new Lab::Instrument::Yokogawa7651({
      connection_type => 'LinuxGPIB',
      gpib_board      => $board,
      gpib_address    => $address,

      gate_protect    => $gp,
      [...]
});
```

METHODS

configure

```
$self->configure(\%config);
```

Supported configure options:

In general, all parameters which can be changed by access methods of the class/object can be used. In fact this is what happens, and the config hash given to configure() ist just a shorthand for this. The following are equivalent:

```
$source->set_gate_protect(1);
$source->set_gp_max_units_per_second(0.1);
...

$source->configure({ gate_protect=>1, gp_max_units_per_second=>0.1,
    ...)
```

Options in detail:

fast_set

This parameter controls the return value of the set_voltage function and can be set to 0 (off, default) or 1 (on). For fast_set off, set_voltage first requests the hardware to set the voltage, and then reads out the actually set voltage via get_voltage. The resulting number is returned. For fast_set on, set_voltage requests the hardware to set the voltage and returns without double-check the requested value. This, albeit less secure, may speed up measurements a lot.

gate_protect

Whether to use the automatic sweep speed limitation. Can be set to 0 (off) or 1 (on). If it is turned on, the output voltage will not be changed faster than allowed by the `gp_max_units_per_second`, `gp_max_units_per_step` and `gp_max_step_per_second` values. These three parameters overdefine the allowed speed. Only two parameters are necessary. If all three are set, the smallest allowed sweep rate is chosen.

Additionally the maximal and minimal output voltages are limited.

This mechanism is useful to protect sensible samples that are destroyed by abrupt voltage changes. One example is gate electrodes on semiconductor electronics samples, hence the name.

gp_max_units_per_second

How much the output voltage is allowed to change per second.

gp_max_units_per_step

How much the output voltage is allowed to change per step.

gp_max_step_per_second

How many steps are allowed per second.

gp_min_units

The smallest allowed output voltage.

gp_max_units

The largest allowed output voltage.

gp_equal_level

Voltages with a difference less than this value are considered equal.

set_level

```
$new_volt=$self->set_level($srclvl);
```

Sets the output to `$srclvl` (in Volts or Ampere). If the configure option `gate_protect` is set to a true value, the safety mechanism takes into account the `gp_max_units_per_step`, `gp_max_units_per_second` etc. settings, by employing the `sweep_to_level` method.

Returns for `fast_set` off the actually set output source level. This can be different from `$srclvl`, due to the `gp_max_units`, `gp_min_units` settings. For `fast_set` on, `set_level` returns always `$level`.

For a multi-channel device, add the channel number as a parameter:

```
$new_volt=$self->set_voltage($voltage,$channel);
```

_set_level($targetlvl) Function Stub. Has to be overwritten by device driver.

The function should set the source level to $targetlvl on the device. Should return the newly set source level.

get_level() Function Stub. Has to be overwritten by device driver.

The function should return the source level from the device cache. If called with the option `from_device => 1` , the value should be fetched from the device. Should return the current source level.

get_range() Function Stub. Has to be overwritten by device driver.

The function should return the source range from the device cache. If called with the option `from_device => 1` , the value should be fetched from the device. Should return the current source range.

set_range() Function Stub. Has to be overwritten by device driver.

The function should set the source range on the device. Should return the newly set source range.

sweep_to_level

```
$new_volt=$self->sweep_to_level($srclvl);
$new_volt=$self->sweep_to_level($srclvl,$channel);
```

This method sweeps the output source level to the desired value and only returns then. If the specific Instrument implemented _sweep_to_level, this version is preferred.

Returns the actually set output source level. This can be different from `$srclvl`, due to the `gp_max_units`, `gp_min_units` settings.

get_level

```
$new_volt=$self->get_level();
$new_volt=$self->get_level($channel);
```

Returns the source level currently set.

create_subsource

```
$bigc2 = $bigsource->create_subsource( channel=>2,
    gp_max_units_per_second=>0.01 );

Returns a new instrument object with its default channel set to
    channel $channel_nr of the parent multi-channel source.
The device_settings given to the parent at instantiation (or the
    default_device_settings if present) will be used as default
values, which can be overwritten by parameters to create_subsource().
```

Lab::Instrument::DummySource

Dummy voltage source

DESCRIPTION The Lab::Instrument::DummySource class implements a dummy voltage source that does nothing but can be used for testing purposes.

Only developers will ever make use of this class.

Lab::Instrument::Yokogawa7651

Yokogawa 7651 DC source

SYNOPSIS

```
use Lab::Instrument::Yokogawa7651;

my $gate14=new Lab::Instrument::Yokogawa7651(
  connection_type => 'LinuxGPIB',
  gpib_address => 22,
  gate_protecet => 1,
  level => 0.5,
);
$gate14->set_voltage(0.745);
print $gate14->get_voltage();
```

DESCRIPTION The Lab::Instrument::Yokogawa7651 class implements an interface to the discontinued voltage and current source 7651 by Yokogawa. This class derives from *Lab::Instrument::Source* and provides all functionality described there.

CONSTRUCTORS

new(%configuration_HASH) HASH is a list of tuples given in the format
key => value,
please supply at least the configuration for the connection: connection_type => "LinxGPIB" gpib_address =>
you might also want to have gate protect from the start (the default values are given):

```
gate_protect => 1,

gp_equal_level          => 1e-5,
gp_max_units_per_second  => 0.05,
gp_max_units_per_step    => 0.005,
gp_max_step_per_second  => 10,
gp_max_units_per_second  => 0.05,
gp_max_units_per_step    => 0.005,

max_sweep_time=>3600,
min_sweep_time=>0.1,
```

If you want to use the sweep function without using gate protect, you should specify

```
stepsize=>0.01
```

Additinally there is support to set parameters for the device "on init":

```
function                        => Voltage, # specify "
    Voltage" or "Current" mode, string is case
    insensitive
range                   => undef,
level                   => undef,
output                                  => undef,
```

If those values are not specified, the current device configuration is left unaltered.

METHODS

set_voltage

```
$src->set_voltage($voltage)
```

Sets the output voltage to $voltage. Returns the newly set voltage.

get_voltage Returns the currently set $voltage. The value is read from the driver cache by default. Provide the option

```
device_cache => 1
```

to read directly from the device.

set_current

```
$src->set_current($current)
```

Sets the output current to $current. Returns the newly set current.

get_current Returns the currently set $current. The value is read from the driver cache by default. Provide the option

```
device_cache => 1
```

to read directly from the device.

set_level

```
$src->set_level($lvl)
```

Sets the level $lvl in the current operation mode.

get_level

```
$lvl = $src->get_level()
```

Returns the currently set level. Use

```
device_cache => 1
```

to enforce a reading directly from the device.

sweep_to_level

```
$src->sweep_to_level($lvl,$time)
```

Sweep to the level $lvl in $time seconds.

set_range

```
$src->set_range($range)
```

Set the output range for the device. $range should be either in decimal or scientific notation. Returns the newly set range.

get_info Returns the information provided by the instrument's 'OS' command, in the form of an array with one entry per line. For display, use join(',',$yoko->get_info()); or similar.

set_output

```
$src->set_output( $onoff )
```

Sets the output switch to "1" (on) or "0" (off). Returns the new output state;

get_output Returns the status of the output switch (0 or 1).

set_voltage_limit($limit)

set_current_limit($limit)

get_status() Returns a hash with the following keys:

```
CAL_switch
memory_card
calibration_mode
output
unstable
error
execution
setting
```

The value for each key is either 0 or 1, indicating the status of the instrument.

INSTRUMENT SPECIFICATIONS

DC voltage The stability (24h) is the value at 23 +- 1°C. The stability (90days), accuracy (90days) and accuracy (1year) are values at 23 +- 5°C. The temperature coefficient is the value at 5 to 18°C and 28 to 40°C.

Range	Maximum Output	Resolution	Stability 24h +-(% of setting + V)	Stability 90d +-(% of setting + V)
10mV	+-12.0000mV	100nV	0.002 + 3	0.014 + 4
100mV	+-120.000mV	1 V	0.003 + 3	0.014 + 5
1V	+-1.20000V	10 V	0.001 + 10	0.008 + 50
10V	+-12.0000V	100 V	0.001 + 20	0.008 + 100
30V	+-32.000V	1mV	0.001 + 50	0.008 + 200

Range	Accuracy 90d +-(% of setting + V)	Accuracy 1yr +-(% of setting + V)	Temperature Coefficient +-(% of setting + V)/ C
10mV	0.018 + 4	0.025 + 5	0.0018 + 0.7
100mV	0.018 + 10	0.025 + 10	0.0018 + 0.7
1V	0.01 + 100	0.016 + 120	0.0009 + 7
10V	0.01 + 200	0.016 + 240	0.0008 + 10
30V	0.01 + 500	0.016 + 600	0.0008 + 30

Range	Maximum Output	Output Resistance	Output Noise DC to 10Hz (typical data)	DC to 10kHz
10mV	-	approx. 2Ohm	3 Vp -p	30 Vp -p
100mV	-	approx. 2Ohm	5 Vp -p	30 Vp -p
1V	+-120mA	less than 2mOhm	15 Vp -p	60 Vp -p
10V	+-120mA	less than 2mOhm	50 Vp -p	100 Vp -p
30V	+-120mA	less than 2mOhm	150 Vp -p	200 Vp -p

Common mode rejection: 120dB or more (DC, 50/60Hz). (However, it is 100dB or more in the 30V range.)

DC current

Range	Maximum Output	Resolution	Stability (24 h) +-(% of setting + A)	Stability (90 days) +-(% of setting + A)
1mA	+-1.20000mA	10nA	0.0015 + 0.03	0.016 + 0.1
10mA	+-12.0000mA	100nA	0.0015 + 0.3	0.016 + 0.5
100mA	+-120.000mA	1 A	0.004 + 3	0.016 + 5

Range	Accuracy (90 days) +-(% of setting + A)	Accuracy (1 year) +-(% of setting + A)	Temperature Coefficient +-(% of setting + A)/ C

```
-----   ------------------------------------------------------
1mA     0.02 + 0.1          0.03 + 0.1          0.0015 + 0.01
10mA    0.02 + 0.5          0.03 + 0.5          0.0015 + 0.1
100mA   0.02 + 5            0.03 + 5            0.002  + 1

Range   Maximum     Output                  Output  Noise
        Output      Resistance          DC to 10Hz  DC to 10kHz
                                                    (typical data)
-----------------------------------------------------------------
1mA     +-30 V      more than 100MOhm   0.02 Ap -p   0.1 Ap -p
10mA    +-30 V      more than 100MOhm   0.2 Ap -p    0.3 Ap -p
100mA   +-30 V      more than 10MOhm    2 Ap -p      3 Ap -p
```

Common mode rejection: 100nA/V or more (DC, 50/60Hz).

Lab::Instrument::YokogawaGS200

Yokogawa GS200 DC source

SYNOPSIS

```
use Lab::Instrument::YokogawaGS200;

my $gate14=new Lab::Instrument::YokogawaGS200(
  connection_type => 'LinuxGPIB',
  gpib_address => 22,
  function => 'VOLT',
  level => 0.4,
);
$gate14->set_voltage(0.745);
print $gate14->get_voltage();
```

DESCRIPTION The Lab::Instrument::YokogawaGS200 class implements an interface to the discontinued voltage and current source GS200 by Yokogawa. This class derives from *Lab::Instrument::Source* and provides all functionality described there.

CONSTRUCTORS

new(%configuration_HASH) HASH is a list of tuples given in the format
key => value,
please supply at least the configuration for the connection: connection_type => "LinxGPIB" gpib_address =>
you might also want to have gate protect from the start (the default values are given):

```
gate_protect => 1,

gp_equal_level          => 1e-5,
gp_max_units_per_second  => 0.05,
gp_max_units_per_step    => 0.005,
gp_max_step_per_second  => 10,
gp_max_units_per_second  => 0.05,
gp_max_units_per_step    => 0.005,

max_sweep_time=>3600,
min_sweep_time=>0.1,
```

Additinally there is support to set parameters for the device "on init":

```
function                        => undef, # 'VOLT' -
    voltage, 'CURR' - current
range                   => undef,
level                   => undef,
output                                  => undef,
```

If those values are not specified, they are read from the device.

METHODS

sweep_to_level

```
$src->sweep_to_level($lvl,$time)
```

Sweep to the level $lvl in $time seconds.

set_voltage

```
$src->set_voltage($voltage)
```

Sets the output voltage to $voltage. Returns the newly set voltage.

get_voltage Returns the currently set $voltage. The value is read from the driver cache by default. Provide the option

```
device_cache => 1
```

to read directly from the device.

set_current

```
$src->set_current($current)
```

Sets the output current to $current. Returns the newly set current.

get_current Returns the currently set $current. The value is read from the driver cache by default. Provide the option

```
device_cache => 1
```

to read directly from the device.

set_level

```
$src->set_level($lvl)
```

Sets the level $lvl in the current operation mode.

get_level

```
$lvl = $src->get_level()
```

Returns the currently set level. Use

```
device_cache => 1
```

to enforce a reading directly from the device.

set_range($range)

```
Fixed voltage mode
10E-3     10mV
100E-3    100mV
1E+0      1V
10E+0     10V
30E+0     30V

Fixed current mode
1E-3                1mA
10E-3       10mA
100E-3      100mA
200E-3              200mA

Please use the format on the left for the range command.
```

program_run($program) Runs a program stored on the YokogawaGS200. If no prgram name is given, the currently loaded program is executed.

program_pause Pauses the currently running program.

program_continue Continues the paused program.

set_function($function) Sets the source function. The Yokogawa supports the values
"CURR" for current mode and "VOLT" for voltage mode.
Returns the newly set source function.

set_voltage_limit($limit) Sets a voltage limit to protect the device. Returns the new voltage limit.

set_current_limit($limit) See set_voltage_limit.

output_on() Sets the output switch to on and returns the new value of the output status.

output_off() Sets the output switch to off. The instrument outputs no voltage or current then, no matter what voltage you set. Returns the new value of the output status.

get_error() Queries the error code from the device. This is a very useful thing to do when you are working remote and the source is not responding.

get_output()

get_range()

Lab::Instrument::KnickS252

Knick S 252 DC source

SYNOPSIS

```
use Lab::Instrument::KnickS252;

my $gate14=new Lab::Instrument::KnickS252(0,11);
$gate14->set_range(5);
$gate14->set_voltage(0.745);
print $gate14->get_voltage();
```

DESCRIPTION The Lab::Instrument::KnickS252 class implements an interface to the Knick S 252 dc calibrator. This class derives from *Lab::Instrument::Source* and provides all functionality described there.

CONSTRUCTOR

```
$knick=new Lab::Instrument::KnickS252($gpib_board,$gpib_addr);
# Or any other type of construction supported by Lab::Instrument.
```

METHODS

set_voltage

```
$knick->set_voltage($voltage);
```

get_voltage

```
$voltage=$knick->get_voltage();
```

set_range

```
$knick->set_range($range);
# $range is 5 or 20
#  5   is 5V
# 20   is 20V
```

get_range

```
$range=$knick->get_range();
# $range is 5 or 20
#  5   is 5V
# 20   is 20V
```

1.11.4 Lock-in amplifiers

Lab::Instrument::SR830

Stanford Research SR830 Lock-In Amplifier

SYNOPSIS

```
use Lab::Instrument::SR830;

my $sr=new Lab::Instrument::SR830(
   connection_type=>'LinuxGPIB',
   gpib_address=>12,
);

($x,$y) = $sr->get_xy();
($r,$phi) = $sr->get_rphi();
```

DESCRIPTION The Lab::Instrument::SR830 class implements an interface to the Stanford Research SR830 Lock-In Amplifier.

CONSTRUCTOR

```
$sr830=new Lab::Instrument::SR830($board,$gpib);
```

METHODS

get_xy

```
($x,$y)= $sr830->get_xy();
```

Reads channels x and y simultaneously; returns an array.

get_rphi

```
($r,$phi)= $sr830->get_rphi();
```

Reads amplitude and phase simultaneously; returns an array.

set_sens

```
$string=$sr830->set_sens(1E-7);
```

Sets sensitivity (value given in V); possible values are: 2 nV, 5 nV, 10 nV, 20 nV, 50 nV, 100 nV, ..., 100 mV, 200 mV, 500 mV, 1V If the argument is not in this list, the next higher value will be chosen.

Returns the value of the sensitivity that was actually set, as number in Volt.

get_sens

```
$sens = $sr830->get_sens();
```

Returns the value of the sensitivity, as number in Volt.

set_tc

```
$string=$sr830->set_tc(1E-3);
```

Sets time constant (value given in seconds); possible values are: 10 us, 30us, 100 us, 300 us, ..., 10000 s, 30000 s If the argument is not in this list, the next higher value will be chosen.

Returns the value of the time constant that was actually set, as number in seconds.

get_tc

```
$tc = $sr830->get_tc();
```

Returns the time constant, as number in seconds.

set_frequency

```
$sr830->set_frequency(334);
```

Sets reference frequency; value given in Hz. Values between 0.001 Hz and 102 kHz can be set.

get_frequency

```
$freq=$sr830->get_frequency();
```

Returns reference frequency in Hz.

set_amplitude

```
$sr830->set_amplitude(0.005);
```

Sets output amplitude to the value given (in V); values between 4 mV and 5 V are possible.

get_amplitude

```
$ampl=$sr830->get_amplitude();
```

Returns amplitude of the sine output in V.

id

```
$id=$sr830->id();
```

Returns the instruments ID string.

1.11.5 RF generators

Lab::Instrument::HP83732A

HP 83732A Series Synthesized Signal Generator

SYNOPSIS

DESCRIPTION

CONSTRUCTOR

METHODS

1.11.6 RF detectors

Lab::Instrument::U2000

Agilent U2000 series USB Power Sensor

DESCRIPTION The Lab::Instrument::U2000 class implements an interface to the U2000 series power sensors from Agilent.

CONSTRUCTOR

```
my $power=new(\%options);
```

METHODS

get_value

```
$value=$power->read();
```

Read out the current measurement value, for whatever type of measurement the sensor is currently configured. Waits for trigger.

id

```
$id=$power->id();
```

Returns the instruments ID string.

set_sample_rate $power->set_sample_rate(string); Valid values are MIN, MAX, NORM, DOUBLE, FAST and 1-110 (rate in Hz).

set_step_detect $power->set_step_detect(string); Valid values are ON and OFF.

set_frequency $power->set_frequency(string or number) Sets frequency for internal frequency correction (in Hz). Valid values are DEF, MIN, MAX and 1kHz to 1000GHz.

1.11.7 Superconducting magnet power supplies

Lab::Instrument::MagnetSupply

Base class for magnet power supply instruments

```
(c) 2010 David Borowsky, Andreas K. H ttel
    2011 Andreas K. H ttel
```

Lab::Instrument::OI_IPS

Oxford Instruments IPS series superconducting magnet supply

Tested with the Oxford Instruments IPS 120-10 and IPS 180 superconducting magnet power supplies.

(c) 2010, 2011, 2012 Andreas K. H ttel

Lab::Instrument::Cryogenic

Cryogenic SMS120 superconducting magnet supply

(c) 2013 David Borowsky
Andreas K. H ttel

1.11.8 Temperature control devices

Lab::Instrument::TemperatureControl

Base class for temperature control instruments

(c) 2011 Andreas K. H ttel

Lab::Instrument::TRMC2

ABB TRMC2 temperature controller

SYNOPSIS

```
use Lab::Instrument::TRMC2;
```

DESCRIPTION The Lab::Instrument::ILM class implements an interface to the ABB TRMC2 temperature controller. The driver works, but documentation is lacking.

CONSTRUCTOR

```
my $trmc=...
```

Lab::Instrument::OI_ITC503

Oxford Instruments ITC503 Intelligent Temperature Control

SYNOPSIS

```
use Lab::Instrument::OI_ITC503;

my $itc=new Lab::Instrument::OI_ITC503(
    isobus_address=>3,
);
```

DESCRIPTION The Lab::Instrument::OI_ITC503 class implements an interface to the Oxford Instruments ITC intelligent temperature controller (tested with the ITC503). This driver is still work in progress and also lacks documentation.

Lab::Instrument::TLK43

Electronic process controller TLKA41/42/43 (SIKA GmbH)

SYNOPSIS

```
use Lab::Instrument::TLK43;

my $tlk=new Lab::Instrument::TLK43({ Port => '/dev/ttyS0',
    slave_address => 1, Baudrate => 19200, Parity => 'none',
    Databits => 8, Stopbits => 1, Handshake => 'none'  });

    or

    my $Bus = new Lab::Bus::MODBUS({ Port => '/dev/ttyS0', Interface
        => 'RS232', slave_address => 1, Baudrate => 19200, Parity
       => 'none', Databits => 8, Stopbits => 1, Handshake => 'none'
        });
    my $tlk=new Lab::Instrument::TLK43({ Bus => $Bus });

print $tlk->read_temperature();
    $tlk->set_setpoint(200);
```

DESCRIPTION The Lab::Instrument::TLK43 class implements an interface to SIKA GmbH's TLK41/42/43 process controllers. The devices have to be equipped with the optional RS485 interface. The device can be fully programmed using RS232 and an interface converter (e.g. "GRS 485 ISO" RS232 - RS485 Converter).

The following parameter list configures the RS232 port correctly for a setup with the GRS485 converter and a speed of 19200 baud: Port => '/dev/ttyS0', Interface => 'RS232', Baudrate => 19200, Parity => 'none', Databits => 8, Stopbits => 1, Handshake => 'none'

CONSTRUCTOR

```
my $tlk=new(\%options);
```

METHODS

read_temperature

```
$temp = read_temperature();
```

Returns the currently measured temperature, or undef on errors.

set_setpoint

```
$success=$tlk->set_setpoint({ Slot => $Slot, Value => $Value })
```

Set the value of setpoint slot $Slot.

$Slot

The TLK controllers provide 4 setpoint slots. $Slot has to be a number of (1..4) and may not exceed the nSP-parameter set in the device (set_setpoint return undef in this case)

$Value

Float value to set the setpoint to. Internally this is held by a 16bit number. set_setpoint() will cut off the decimal values according to the value of the "dP" parameter of the device. (dP=0..3 meaning 0..3 decimal points. only 0,1 work for temperature sensors)

set_active_setpoint

```
$success=$tlk->set_active_setpoint($Value);
```

Set the value of the currently active setpoint slot.

$Value

Float value to set the setpoint to. Internally this is held by a 16bit number. set_setpoint() will cut off the decimal values according to the value of the "dP" parameter of the device. (dP=0..3 meaning 0..3 decimal points. only 0,1 work for temperature sensors)

read_range

```
$value=$tlk->read_range({ mem_addresss => (0x0200..0xFFFF || Name),
    MemCount => (1..4) })
```

Read the values of $MemCount memory slots from $mem_address on. The Address may be specified as a 16bit Integer in the valid range, or as an address name (see TLK43.pm, %fields{'MemTable'}). $MemCount may be in the range 1..4. Returns the memory as an array (one byte per field)

read_address_int

```
$value=$tlk->read_range({ mem_addresss => (0x0200..0xFFFF || Name),
    MemCount => (1..4) })
```

Read the value of the 16bit word at $mem_address on. The Address may be specified as a 16bit Integer in the valid range, or as an address name (see TLK43.pm, %fields{'MemTable'}). Returns the value as unsigned integer (internally (byte1 << 8) + byte2)

write_address

```
$success=$tlk->write_address({ mem_address => (0x0200...0xFFFF ||
    Name), mem_value => Value (16 bit word) });
```

Write $Value to the given address. The Address may be specified as a 16bit Integer in the valid range, or as an address name (see TLK43.pm, %fields{'MemTable'}).

set_setpoint_slot

```
$success=$tlk->set_setpoint_slot({ Slot => $Slot })
```

Set the active setpoint to slot no. $Slot.

$Slot

The TLK controllers provide 4 setpoint slots. $Slot has to be a number of (1..4) and may not exceed the nSP-parameter set in the device (set_setpoint_slot return undef in this case)

1.11.9 Cryostat handling devices

Lab::Instrument::OI_ILM210

Oxford Instruments ILM Intelligent Level Meter

SYNOPSIS

```
use Lab::Instrument::OI_ILM210;

my $ilm=new Lab::Instrument::OI_ILM210(
  connection_type=>'IsoBus',
  base_connection=>...,
  isobus_address=>5,
);
```

DESCRIPTION The Lab::Instrument::OI_ILM210 class implements an interface to the Oxford Instruments ILM helium level meter (tested with the ILM210).

CONSTRUCTOR

```
my $ilm=new Lab::Instrument::OI_ILM210(
  connection_type=>'IsoBus',
  base_connection=> $iso,
  isobus_address=> $addr,
);
```

Instantiates a new ILM210 object, attached to the GPIB or RS232 connection (of type `Lab::Connection`) `$iso`, with IsoBus address `$addr`.

METHODS

get_level

```
$perc=$ilm->get_level();
$perc=$ilm->get_level(1);
```

Reads out the current helium level in percent. Note that this command does NOT trigger a measurement, but only reads out the last value measured by the ILM. This means that in slow mode values may remain constant for several minutes.

As optional parameter a channel number can be provided. This defaults to 1.

Lab::Instrument::OI_Mercury

Oxford Instruments Mercury Cryocontrol

SYNOPSIS

```
use Lab::Instrument::OI_Mercury;

my $m=new Lab::Instrument::OI_Mercury(
  connection_type=>'Socket',
  remote_port=>7020,
  remote_addr=>1.2.3.4,
);
```

DESCRIPTION The Lab::Instrument::OI_Mercury class implements an interface to the Oxford Instruments Mercury cryostat control system.

METHODS

get_catalogue

```
$mcat=$m->get_catalogue();
print "$mcat\n";
```

Returns the hardware configuration of the Mercury system. A typical response would be

```
STAT:SYS:CAT:DEV:GRPX:PSU:DEV:MB1.T1:TEMP:DEV:GRPY:PSU:DEV:GRPZ:PSU:
    DEV:PSU.M1:PSU:DEV:PSU.M2:PSU:DEV:GRPN:PSU:DEV:DB5.L1:LVL
```

Here, each group starting with "DEV:" describes one hardware component. In this case, we obtain for example:

```
DEV:GRPX:PSU      |
DEV:GRPY:PSU      |- a 3-axis magnet power supply unit
DEV:GRPZ:PSU      |
DEV:MB1.T1:TEMP   -- a temperature sensor
DEV:DB5.L1:LVL    -- a cryogen level sensor
```

In each of these blocks, the second component after "DEV:" is the UID of the device; it can be used in other commands such as get_level to address it.

get_temperature

```
$t=$m->get_temperature('MB1.T1');
```

Read out the designated temperature channel. Result is in Kelvin (?).

get_he_level

```
$he=$m->get_he_level('DB5.L1');
```

Read out the designated liquid helium level meter channel. Result is in percent as calibrated.

1.11.10 Stepper motors

Lab::Instrument::PD11042

42mm stepper motor with integrated controller/driver

SYNOPSIS

```
use Lab::Instrument::PD11042;

...
```

DESCRIPTION The Lab::Instrument::PD11042 class implements an interface to the Trinamic PD-110-42 low-cost 42mm stepper motor with integrated controller/driver.

CONSTRUCTOR

...

METHODS

...

...

...

1.12 Connection classes

1.12.1 Lab::Connection

Connection base class

SYNOPSIS

This is the base class for all connections. Every inheriting classes constructors should start as follows:

```
sub new {
        my $proto = shift;
        my $class = ref($proto) || $proto;
        my $self = $class->SUPER::new(@_);
        $self->_construct(__PACKAGE__); #initialize fields etc.
        ...
}
```

DESCRIPTION

`Lab::Connection` is the base class for all connections and implements a generic set of access methods. It doesn't do anything on its own.

A connection in general is an object which is created by an instrument and provides it with a generic set of methods to talk to its hardware counterpart. For example *Lab::Instrument::HP34401A* can work with any connection of the type GPIB, that is, connections derived from Lab::Connection::GPIB.

That would be, for example Lab::Connection::LinuxGPIB Lab::Connection::VISA_GPIB

Towards the instrument, these look the same, but they work with different drivers/backends.

CONSTRUCTOR

new Generally called in child class constructor:

```
my $self = $class->SUPER::new(@_);
```

Return blessed $self, with @_ accessible through $self->Config().

METHODS

Clear Try to clear the connection, if the bus supports it.

Read

```
my $result = $connection->Read();
my $result = $connection->Read( timeout => 30 );

configuration hash options:
 brutal => <1/0>   # suppress timeout errors if set to 1
 read_length => <int>   # how many bytes/characters to read
 ...see bus documentation
```

Reads a string from the connected device. In this basic form, its merely a wrapper to the method connection_read() of the used bus. You can give a configuration hash, which options are passed on to the bus. This hash is also meant for options to Read itself, if need be.

Write

```
$connection->Write( command => '*CLS' );

configuration hash options:
 command => <command string>
 ...more (see bus documentation)
```

Write a command string to the connected device. In this basic form, its merely a wrapper to the method connection_write() of the used bus. You need to supply a configuration hash, with at least the key 'command' set. This hash is also meant for options to Read itself, if need be.

Query

```
my $result = $connection->Query( command => '*IDN?' );

configuration hash options:
 command => <command string>
 wait_query => <wait time between read and write in seconds>   #
     overwrites the connection default
 brutal => <1/0>   # suppress timeout errors if set to true
 read_length => <int>   # how many bytes/characters to read
 ...more (see bus documentation)
```

Write a command string to the connected device, and immediately read the response. You need to supply a configuration hash with at least the 'command' key set. The wait_query key sets the time to wait between read and write in usecs. The hash is also passed along to the used bus methods.

BrutalRead The same as read with the 'brutal' option set to 1.

BrutalQuery The same as Query with the 'brutal' option set to 1.

LongQuery The same as Query with 'read_length' set to 10240.

config Provides unified access to the fields in initial @_ to all the cild classes. E.g.

```
$GPIB_Address=$instrument->Config(gpib_address);
```

Without arguments, returns a reference to the complete $self->Config aka @_ of the constructor.

```
$Config = $connection->Config();
$GPIB_Address = $connection->Config()->{'gpib_address'};
```

1.12.2 Lab::Connection::DEBUG

Debug connection

DESCRIPTION

Connection to the DEBUG bus.

1.12.3 Lab::Connection::GPIB

Base class for GPIB connections

SYNOPSIS

This is the base class for all connections providing a GPIB interface. Every inheriting class constructor should start as follows:

```
sub new {
        my $proto = shift;
        my $class = ref($proto) || $proto;
        my $self = $class->SUPER::new(@_);
        $self->_construct(__PACKAGE__); #initialize fields etc.
        ...
}
```

DESCRIPTION

`Lab::Connection::GPIB` is the base class for all connections providing a GPIB interface. It is not usable on its own. It inherits from *Lab::Connection*.

Its main use so far is to define the data fields common to all GPIB interfaces.

CONSTRUCTOR

new Generally called in child class constructor:

```
my $self = $class->SUPER::new(@_);
```

Return blessed $self, with @_ accessible through $self->Config().

METHODS

This just calls back on the methods inherited from Lab::Connection.

If you inherit this class in your own connection however, you have to provide the following methods. Take a look at e.g. Lab::Connection::VISA_GPIB and at the basic implementations in *Lab::Connection* (they may even suffice).

Write() Takes a config hash, has to at least pass the key 'command' correctly to the underlying bus.

Read() Takes a config hash, reads back a message from the device.

Clear() Clears the instrument.

config Provides unified access to the fields in initial @_ to all the child classes. E.g.

```
$GPIB_PAddress=$instrument->Config(GPIB_PAddress);
```

Without arguments, returns a reference to the complete $self->Config aka @_ of the constructor.

```
$Config = $connection->Config();
$GPIB_PAddress = $connection->Config()->{'GPIB_PAddress'};
```

1.12.4 Lab::Connection::RS232

Base class for RS232 connections

SYNOPSIS

This is the base class for all connections providing a RS232 interface. Every inheriting class constructor should start as follows:

```
sub new {
        my $proto = shift;
        my $class = ref($proto) || $proto;
        my $self = $class->SUPER::new(@_);
        $self->_construct(__PACKAGE__); #initialize fields etc.
        ...
}
```

DESCRIPTION

`Lab::Connection::RS232` is the base class for all connections providing a GPIB interface. It is not usable on its own. It inherits from *Lab::Connection*.

CONSTRUCTOR

new Generally called in child class constructor:

```
my $self = $class->SUPER::new(@_);
```

Return blessed $self, with @_ accessible through $self->Config().

METHODS

This just calls back on the methods inherited from Lab::Connection.

If you inherit this class in your own connection however, you have to provide the following methods. Take a look at e.g. Lab::Connection::VISA_RS232 and at the basic implementations in *Lab::Connection* (they may even suffice).

Write() Takes a config hash, has to at least pass the key 'command' correctly to the underlying bus.

Read() Takes a config hash, reads back a message from the device.

Clear() Clears the instrument.

config Provides unified access to the fields in initial @_ to all the child classes. E.g.

1.12.5 Lab::Connection::LinuxGPIB

Connection class which uses LinuxGPIB (libgpib0) as a backend.

SYNOPSIS

This is not called directly. To make a GPIB suppporting instrument use Lab::Connection::LinuxGPIB, set the connection_type parameter accordingly:

$instrument = new HP34401A(connection_type => 'LinuxGPIB', gpib_board => 0, gpib_address => 14)

DESCRIPTION

`Lab::Connection::LinuxGPIB` provides a GPIB-type connection with the bus *Lab::Bus::LinuxGPIB*, using Linux GPIB (aka libgpib0 in debian) as backend.

It inherits from *Lab::Connection::GPIB* and subsequently from *Lab::Connection*.

For *Lab::Bus::LinuxGPIB*, the generic methods of *Lab::Connection* suffice, so only a few defaults are set: wait_status=>0, # usec; wait_query=>10, # usec; read_length=>1000, # bytes

CONSTRUCTOR

new

```
my $connection = new Lab::Connection::LinuxGPIB(
   gpib_board => 0,
   gpib_address => $address,
   gpib_saddress => $secondary_address
}
```

METHODS

This just falls back on the methods inherited from *Lab::Connection*.

config Provides unified access to the fields in initial @_ to all the child classes. E.g.

```
$GPIB_Address=$instrument->Config(gpib_address);
```

Without arguments, returns a reference to the complete $self->Config aka @_ of the constructor.

```
$Config = $connection->Config();
$GPIB_Address = $connection->Config()->{'gpib_address'};
```

1.12.6 Lab::Connection::MODBUS_RS232

Connection class for Lab::Bus::MODBUS_RS232

1.12.7 Lab::Connection::VISA

VISA-type connection class which uses *Lab::Bus::VISA* and thus NI VISA (*Lab::VISA*) as a backend.

SYNOPSIS

This is not called directly. To make a VISA suppporting instrument use Lab::Connection::VISA, set the connection_type parameter accordingly:

$instrument = new HP34401A(connection_type => 'VISA', resource_name => 'GPIB0::14::INSTR',)

DESCRIPTION

`Lab::Connection::VISA` provides a VISA-type connection with *Lab::Bus::VISA* using NI VISA (*Lab::VISA*) as backend.

It inherits from *Lab::Connection*.

CONSTRUCTOR

new

```
my $connection = new Lab::Connection::VISA(
  connection_type => 'VISA',
  resource_name => 'GPIB0::14::INSTR',
}
```

METHODS

This just falls back on the methods inherited from *Lab::Connection*.

config Provides unified access to the fields in initial @_ to all the child classes. E.g.

```
$GPIB_Address=$instrument->Config(gpib_address);
```

Without arguments, returns a reference to the complete $self->Config aka @_ of the constructor.

```
$Config = $connection->Config();
$GPIB_Address = $connection->Config()->{'gpib_address'};
```

1.12.8 Lab::Connection::VISA_GPIB

GPIB-type connection class which uses *Lab::Bus::VISA* and thus NI VISA (*Lab::VISA*) as a backend.

SYNOPSIS

This class is not called directly. To make a GPIB suppporting instrument use Lab::Connection::VISA_GPIB, set the connection_type parameter accordingly:

```
$instrument = new HP34401A(
   connection_type => 'VISA_GPIB',
   gpib_board => 0,
   gpib_address => 14
)
```

DESCRIPTION

`Lab::Connection::VISA_GPIB` provides a GPIB-type connection with *Lab::Bus::VISA* using NI VISA (*Lab::VISA*) as backend.

It inherits from *Lab::Connection::GPIB* and subsequently from *Lab::Connection*.

The main feature is to assemble the standard gpib connection options gpib_board gpib_address gpib_saddress into a valid NI VISA resource name (see *Lab::Connection::VISA* for more details).

CONSTRUCTOR

new

```
my $connection = new Lab::Connection::VISA_GPIB(
   gpib_board => 0,
   gpib_address => $address,
   gpib_saddress => $secondary_address
}
```

METHODS

This just falls back on the methods inherited from *Lab::Connection*.

config Provides unified access to the fields in initial @_ to all the child classes. E.g.

```
$GPIB_Address=$instrument->Config(gpib_address);
```

Without arguments, returns a reference to the complete $self->Config aka @_ of the constructor.

```
$Config = $connection->Config();
$GPIB_Address = $connection->Config()->{'gpib_address'};
```

1.12.9 Lab::Connection::VISA_RS232

RS232-type connection class which uses *Lab::Bus::VISA* and thus NI VISA (*Lab::VISA*) as a backend.

SYNOPSIS

This class is not called directly. To make a RS232 suppporting instrument use Lab::Connection::VISA_RS232, set the connection_type parameter accordingly:

```
$instrument = new BlaDeviceType(
   connection_type => 'VISA_RS232',
   port => 'ASRL1',
)
```

DESCRIPTION

`Lab::Connection::VISA_RS232` provides a RS232-type connection with *Lab::Bus::VISA* using NI VISA (*Lab::VISA*) as backend.

It inherits from *Lab::Connection::RS232* and subsequently from *Lab::Connection*.

The main feature is to set upon initialization all the RS232 libe parameters baud_rate ...

CONSTRUCTOR

new

```
my $connection = new Lab::Connection::VISA_RS232(
   port => 'ASRL1',
   baud_rate => 9600,
)
```

METHODS

This just falls back on the methods inherited from *Lab::Connection*.

config Provides unified access to the fields in initial @_ to all the child classes. E.g.

```
$GPIB_Address=$instrument->Config(gpib_address);
```

Without arguments, returns a reference to the complete $self->Config aka @_ of the constructor.

```
$Config = $connection->Config();
$GPIB_Address = $connection->Config()->{'gpib_address'};
```

1.12.10 Lab::Connection::IsoBus

IsoBus connection class which uses *Lab::Bus::IsoBus* as a backend.

SYNOPSIS

This is not called directly. To make an Isobus instrument use Lab::Connection::IsoBus, set the connection_type parameter accordingly:

$instrument = new ILM210(connection_type => 'IsoBus', isobus_address => 3,)

DESCRIPTION

`Lab::Connection::IsoBus` provides a connection with *Lab::Bus::IsoBus*, transparently handled via a pre-existing bus and connection object (e.g. serial or GPIB).

It inherits from *Lab::Connection*.

CONSTRUCTOR

new

```
my $connection = new Lab::Connection::IsoBus(
  connection_type => 'IsoBus',
  isobus_address => 3,
}
```

METHODS

This just falls back on the methods inherited from *Lab::Connection*.

config Provides unified access to the fields in initial @_ to all the child classes. E.g.

```
$IsoBus_Address=$instrument->Config(isobus_address);
```

Without arguments, returns a reference to the complete $self->Config aka @_ of the constructor.

```
$Config = $connection->Config();
$IsoBus_Address = $connection->Config()->{'isobus_address'};
```

1.12.11 Lab::Connection::LinuxGPIB

Connection class which uses LinuxGPIB (libgpib0) as a backend.

SYNOPSIS

This is not called directly. To make a GPIB suppporting instrument use Lab::Connection::LinuxGPIB, set the connection_type parameter accordingly:

$instrument = new HP34401A(connection_type => 'LinuxGPIB', gpib_board => 0, gpib_address => 14)

DESCRIPTION

`Lab::Connection::LinuxGPIB` provides a GPIB-type connection with the bus *Lab::Bus::LinuxGPIB*, using Linux GPIB (aka libgpib0 in debian) as backend.

It inherits from *Lab::Connection::GPIB* and subsequently from *Lab::Connection*.

For *Lab::Bus::LinuxGPIB*, the generic methods of *Lab::Connection* suffice, so only a few defaults are set: wait_status=>0, # usec; wait_query=>10, # usec; read_length=>1000, # bytes

CONSTRUCTOR

new

```
my $connection = new Lab::Connection::LinuxGPIB(
   gpib_board => 0,
   gpib_address => $address,
   gpib_saddress => $secondary_address
}
```

METHODS

This just falls back on the methods inherited from *Lab::Connection*.

config Provides unified access to the fields in initial @_ to all the child classes. E.g.

```
$GPIB_Address=$instrument->Config(gpib_address);
```

Without arguments, returns a reference to the complete $self->Config aka @_ of the constructor.

```
$Config = $connection->Config();
$GPIB_Address = $connection->Config()->{'gpib_address'};
```

1.13 Bus classes

1.13.1 Lab::Bus

Bus base class

SYNOPSIS

This is a base class for inheriting bus types.

DESCRIPTION

`Lab::Bus` is a base class for individual buses. It does not do anything on its own. For more detailed information on the use of bus objects, take a look on a child class, e.g. *Lab::Bus::LinuxGPIB*.

`Lab::Bus::BusList` contains a hash with references to all the active buses in your program. They are put there by the constructor of the individual bus `Lab::Bus::new()` and have two levels: Package name and a unique bus ID (GPIB board index offers itself for GPIB). This is to transparently (to the use interface) reuse bus objects, as there may only be one bus object for every (hardware) bus. weaken() is used on every reference stored in this hash, so it doesn't prevent object destruction when the last "real" reference is lost. Yes, this breaks object orientation a little, but it comes so handy!

```
our %Lab::Bus::BusList = [
      $Package => {
              $UniqueID => $Object,
      }
      'Lab::Bus::GPIB' => {
              '0' => $Object,          "0" is the gpib board index
      }
```

Place your twin searching code in `$self-`_search_twin()>. Make sure it evaluates `$self-`IgnoreTwin()>. Look at *Lab::Bus::LinuxGPIB*.

CONSTRUCTOR

new Generally called in child class constructor:

```
my $self = $class->SUPER::new(@_);
```

Return blessed $self, with @_ accessible through $self->Config().

METHODS

config Provides unified access to the fields in initial @_ to all the child classes.

connection_new Empty stub function for overloading

connection_read Empty stub function for overloading

connection_write Empty stub function for overloading

1.13.2 Lab::Bus::DEBUG

Interactive debug bus

DESCRIPTION

This will be an interactive debug bus, which prints out the commands sent by the measurement script, and lets you manually enter the instrument responses.

Unfinished, needs testing.

1.13.3 Lab::Bus::DEBUG::HumanInstrument

Interactive debug bus with WxWindow interface

DESCRIPTION

This will be an interactive debug bus, which prints out the commands sent by the measurement script, and lets you manually enter the instrument responses.

Unfinished, needs testing.

1.13.4 Lab::Bus::LinuxGPIB

LinuxGPIB bus

SYNOPSIS

This is the GPIB bus class for the GPIB library `linux-gpib` (aka `libgpib0` in the debian world).

```
my $GPIB = new Lab::Bus::LinuxGPIB({ gpib_board => 0 });
```

or implicit through instrument and connection creation:

```
my $instrument = new Lab::Instrument::HP34401A({
  connection_type => 'LinuxGPIB',
  gpib_board => 0,
  gpib_address=>14,
}
```

DESCRIPTION

See http://linux-gpib.sourceforge.net/ for details on the LinuxGPIB package. The package provides both kernel drivers and Perl bindings. Obviously, this will work for Linux systems only. On Windows, please use *Lab::Bus::VISA*. The interfaces are (errr, will be) identical.

Note: you don't need to explicitly handle bus objects. The Instruments will create them themselves, and existing bus will be automagically reused.

In GPIB, instantiating two bus with identical parameter "gpib_board" will logically lead to the reuse of the first one. To override this, use the parameter "ignore_twins" at your own risk.

CONSTRUCTOR

new

```
my $bus = Lab::Bus::GPIB({
   gpib_board => $board_num
 });
```

Return blessed $self, with @_ accessible through $self->config().
`gpib_board`: Index of board to use. Can be omitted, 0 is the default.

Thrown Exceptions

Lab::Bus::GPIB throws

```
Lab::Exception::GPIBError
  fields:
  'ibsta', the raw ibsta status byte received from linux-gpib
  'ibsta_hash', the ibsta bit values in a named hash ( 'DCAS' => $val,
       'DTAS' => $val, ... ).
                  Use Lab::Bus::GPIB::VerboseIbstatus() to get a nice
                      string representation

Lab::Exception::GPIBTimeout
  fields:
  'Data', this is meant to contain the data that (maybe) has been read
     /obtained/generated despite and up to the timeout.
  ... and all the fields of Lab::Exception::GPIBError
```

METHODS

connection_new

```
$GPIB->connection_new({ gpib_address => $paddr });
```

Creates a new connection ("instrument handle") for this bus. The argument is a hash, whose contents depend on the bus type. For GPIB at least 'gpib_address' is needed.

The handle is usually stored in an instrument object and given to connection_read, connection_write etc. to identify and handle the calling instrument:

```
$InstrumentHandle = $GPIB->connection_new({ gpib_address => 13 });
$result = $GPIB->connection_read($self->InstrumentHandle(), { options
    });
```

See `Lab::Instrument::Read()`.

TODO: this is probably not correct anymore

connection_write

```
$GPIB->connection_write( $InstrumentHandle, { Cmd => $Command } );
```

Sends $Command to the instrument specified by the handle.

connection_read

```
$GPIB->connection_read( $InstrumentHandle, { Cmd => $Command,
    ReadLength => $readlength, Brutal => 0/1 } );
```

Sends $Command to the instrument specified by the handle. Reads back a maximum of $readlength bytes. If a timeout or an error occurs, Lab::Exception::GPIBError or Lab::Exception::GPIBTimeout are thrown, respectively. The Timeout object carries the data received up to the timeout event, accessible through $Exception->Data().

Setting `Brutal` to a true value will result in timeouts being ignored, and the gathered data returned without error.

timeout

```
$GPIB->timeout( $connection_handle, $timeout );
```

Sets the timeout in seconds for GPIB operations on the device/connection specified by $connection_handle.

config Provides unified access to the fields in initial @_ to all the child classes. E.g.

```
$GPIB_Address=$instrument->config(gpib_address);
```

Without arguments, returns a reference to the complete $self->config aka @_ of the constructor.

```
$config = $bus->config();
$GPIB_PAddress = $bus->config()->{'gpib_address'};
```

1.13.5 Lab::Bus::RS232

RS232 or Virtual Comm port bus

SYNOPSIS

```
my $bus = Lab::Bus::RS232({
   port => '/dev/ttyACM0'
});
```

Return blessed $self, with @_ accessible through $self->config().
`port`: Device name to use (e.g. `COM1` under Windows or `/dev/ttyUSB1` under Linux)
TODO: check this!!!

DESCRIPTION

This is a bus for Lab::Measurement to communicate via RS232 or Virtual Comm port e.g. for FTDI devices.

CONSTRUCTOR

new All parameters are used as by `Device::SerialPort`. port is needed in every case. An additional parameter `reuse` is avaliable if two instruments use the same port. This is mainly implemented for USBprologix gateway. `reuse` can be a SerialPort object or a `Lab::Instrument...` package. Default value for timeout is 500ms and can be set by the parameter "timeout". Other options: handshake, baudrate, databits, stopbits and parity

METHODS

Used by `Lab::Instrument`. Not for direct use!!!

Read Reads data.

Write Sent data to instrument

Handle Give instrument object handle

1.13.6 Lab::Bus::MODBUS_RS232

RS232/RS485 MODBUS RTU protocol bus

SYNOPSIS

```
use Lab::Bus::MODBUS_RS232;
my $h = Lab::Bus::MODBUS_RS232->new({
        Interface => 'RS232',
        Port => 'COM1|/dev/ttyUSB1'
        slave_address => '1'
});
```

`COM1` is the Windows notation, `/dev/ttyUSB1` the Linux equivalent. Use as needed.

DESCRIPTION

This is an interface package for Lab::Measurement to communicate via RS232/RS485 with a MODBUS RTU enabled device. It uses Lab::Bus::RS232 (RS485 can be done using a RS232<->RS485 converter for now). It's main use is to calculate the checksums needed by MODBUS RTU.

Refer to your device for the correct port configuration.

As of yet, this driver does NOT fully implement all MODBUS RTU functions. Only the function codes 3 and 6 are provided.

CONSTRUCTOR

new All parameters are used as by `Device::SerialPort` respectively `Lab::Bus::RS232`. 'port' is needed in every case. Default value for timeout is 500ms and can be set by the parameter "Timeout". Other options you probably have to set: Handshake, Baudrate, Databits, Stopbits and Parity.

METHODS

Used by `Lab::Connection`. Not for direct use!!!

connectionRead Reads data. Arguments: function (0x01,0x02,0x03,0x04 - "Read Coils", "Read Discrete Inputs", "Read Holding Registers", "Read Input Registers") slave_address (0xFF) mem_address (0xFFFF, Address of first word) mem_count (0xFFFF, Count of words to read)

connectionWrite Send data to instrument. Arguments:

```
function (0x05,0x06,0x0F,0x10 - "Write Single Coil", "Write Single
    Register", "Write Multiple Coils", "Write Multiple Registers")
```

Currently only 0x06 is implemented.

```
slave_address (0xFF)

mem_address ( 0xFFFF, Address of word )

Value ( 0xFFFF, value to write to mem_address )
```

1.13.7 Lab::Bus::VISA

National Instruments VISA bus

SYNOPSIS

This is the VISA bus class for the NI VISA library.

```
my $visa = new Lab::Bus::VISA();
```

or implicit through instrument creation:

```
my $instrument = new Lab::Instrument::HP34401A({
  BusType => 'VISA',
}
```

DESCRIPTION

soon

CONSTRUCTOR

new

```
my $bus = Lab::Bus::VISA({
});
```

Return blessed $self, with @_ accessible through $self->config().
Options: none

Thrown Exceptions

Lab::Bus::VISA throws

```
Lab::Exception::VISAError
  fields:
  'status', the raw ibsta status byte received from linux-gpib
```

```
Lab::Exception::VISATimeout
  fields:
  'data', this is meant to contain the data that (maybe) has been read
     /obtained/generated despite and up to the timeout.
  ... and all the fields of Lab::Exception::GPIBError
```

METHODS

connection_new

```
$visa->connection_new({ resource_name => "GPIB0::14::INSTR" });
```

Creates a new instrument handle for this bus.

The handle is usually stored in an instrument object and given to connection_read, connection_write etc. to identify and handle the calling instrument:

```
$InstrumentHandle = $visa->connection_new({ resource_name => "GPIB0
    ::14::INSTR" });
$result = $visa->connection_read($self->InstrumentHandle(), { options
    });
```

See `Lab::Instrument::Read()`.

connection_write

```
$visa->connection_write( $InstrumentHandle, { command => $command,
    wait_status => $wait_status } );
```

Sends $command to the instrument specified by the handle, and waits $wait_status microseconds before evaluating the status.

connection_read

```
$visa->connection_read( $InstrumentHandle, { command => $command,
    read_length => $read_length, brutal => 0/1 } );
```

Sends $Command to the instrument specified by the handle. Reads back a maximum of $readlength bytes. If a timeout or an error occurs, Lab::Exception::VISAError or Lab::Exception::VISATimeout are thrown, respectively. The Timeout object carries the data received up to the timeout event, accessible through $Exception->Data().

Setting `Brutal` to a true value will result in timeouts being ignored, and the gathered data returned without error.

connection_query

```
$visa->connection_query( $InstrumentHandle, { command => $command,
    read_length => $read_length, wait_status => $wait_status,
    wait_query => $wait_query, brutal => 0/1 } );
```

Performs an connection_write followed by an connection_read, each given the supplied parameters. Waits $wait_query microseconds betweeen Write and Read.

1.13.8 Lab::Bus::IsoBus

Oxford Instruments IsoBus bus

SYNOPSIS

This is the IsoBus bus class. Typically you create it implicit through instrument creation:

```
my $instrument = new Lab::Instrument::IPS({
  BusType => 'IsoBus',
      base_connection => new Lab::Bus::VISA_GPIB({ gpib_board => 0,
          gpib_address => 24}),
      isobus_addres => 2,
}
```

METHODS

connection_new

```
$isobus->connection_new({ resource_name => $isobus_address });
```

Creates a new instrument handle for this bus.

The handle is usually stored in an instrument object and given to connection_read, connection_write etc. to identify and handle the calling instrument:

```
$InstrumentHandle = $isobus->connection_new({ resource_name =>
    $isobus_address });
$result = $isobus->connection_read($self->InstrumentHandle(), {
    options });
```

See `Lab::Instrument::Read()`.

connection_write

```
$isobus->connection_write( $InstrumentHandle, { command => $command,
    wait_status => $wait_status } );
```

Puts in front of the $command-string the isobus_adress, e.g. "@1$command". Passes the modified argument hash to the base_connection. For further information refer to the specific connection class of $base_connection.

connection_read

```
$isobus->connection_read( $InstrumentHandle, { command => $command,
    read_length => $read_length, timeout => $seconds,  brutal => 0/1 }
     );
```

Puts in front of the $command-string the isobus_adress, e.g. "@1$command". Passes the modified argument hash to the base_connection. For further information refer to the specific connection class of $base_connection.

connection_clear

```
$isobus->connection_clear( $InstrumentHandle );
```

Clears the specified connection $InstrumentHandle.

connection_query

```
$isobus->connection_query( $InstrumentHandle, { command => $command,
    read_length => $read_length, wait_status => $wait_status,
    wait_query => $wait_query, brutal => 0/1 } );
```

Puts in front of the $command-string the isobus_adress, e.g. "@1$command". Passes the modified argument hash to the base_connection. For further information refer to the specific connection class of $base_connection.

1.13.9 Lab::Bus::LinuxGPIB

LinuxGPIB bus

SYNOPSIS

This is the USB TMC (Test & Measurement Class) bus class.

```
my $tmc = new Lab::Bus::USBtmc({ });
```

or implicit through instrument and connection creation:

```
my $instrument = new Lab::Instrument::HP34401A({
  connection_type => 'USBtmc',
  tmc_address=>1,
}
```

DESCRIPTION

Driver for the interface provided by the usbtmc linux kernel module.

Obviously, this will work for Linux systems only. On Windows, please use *Lab::Bus::VISA*. The interfaces are (errr, will be) identical.

Note: you don't need to explicitly handle bus objects. The Instruments will create them themselves, and existing bus will be automagically reused.

CONSTRUCTOR

new

```
my $bus = Lab::Bus::USBtmc({
});
```

Return blessed $self, with @_ accessible through $self->config().

Thrown Exceptions

Lab::Bus::USBtmc throws

```
Lab::Exception::TMCOpenFileError
```

```
Lab::Exception::CorruptParameter
```

METHODS

connection_new

```
$tmc->connection_new({ tmc_address => $addr });
```

Creates a new connection ("instrument handle") for this bus. The argument is a hash, whose contents depend on the bus type. For TMC at least 'tmc_address' is needed.

The handle is usually stored in an instrument object and given to connection_read, connection_write etc. to identify and handle the calling instrument:

```
$InstrumentHandle = $GPIB->connection_new({ gpib_address => 13 });
$result = $GPIB->connection_read($self->InstrumentHandle(), { options
    });
```

See `Lab::Instrument::Read()`.

connection_write

```
$GPIB->connection_write( $InstrumentHandle, { Cmd => $Command } );
```

Sends $Command to the instrument specified by the handle.

connection_read

```
$GPIB->connection_read( $InstrumentHandle, { Cmd => $Command,
    ReadLength => $readlength, Brutal => 0/1 } );
```

Sends $Command to the instrument specified by the handle. Reads back a maximum of $readlength bytes. If a timeout or an error occurs, Lab::Exception::GPIBError or Lab::Exception::Timeout are thrown, respectively. The Timeout object carries the data received up to the timeout event, accessible through $Exception->Data().

Setting `Brutal` to a true value will result in timeouts being ignored, and the gathered data returned without error.

timeout

```
$GPIB->timeout( $connection_handle, $timeout );
```

Sets the timeout in seconds for GPIB operations on the device/connection specified by $connection_handle.

config Provides unified access to the fields in initial @_ to all the child classes. E.g.

```
$GPIB_Address=$instrument->config(gpib_address);
```

Without arguments, returns a reference to the complete $self->config aka @_ of the constructor.

```
$config = $bus->config();
$GPIB_PAddress = $bus->config()->{'gpib_address'};
```

2 The Lab::VISA package

2.1 Lab::VISA::Installation

Installation guide for Lab::VISA

Introduction

Lab::VISA has been tested to work on Linux and Windows, both with ActiveState Perl and the Microsoft VC++ Compiler, and Strawberry Perl with the included gcc compiler.

Installation on Windows XP with ActiveState Perl

Work with administrator account during installation.

Install VISA (and GPIB drivers) if necessary.

- Download current VISA release from NI (tested with 4.4.1, 4.5.0)
- Run installer
- Check location of visa32.lib (eg. C:\Programme\IVI Foundation\VISA\WinNT\lib\msc\visa32.lib) and remember for later.

Install Microsoft Visual C++ from http://www.microsoft.com/express/Downloads/

From now on run all commandline programs during installation only from the "Visual Studio Command line", which can be found in the Start menu.

Install Perl.

- Tested with ActivePerl from http://www.activestate.com/Products/activeperl/index.mhtml
- Make sure to include Perl Package Manager.
- Make sure to activate the check box to include perl directory in PATH variable.

Install gnuplot (not mandatory)

- Download from http://sourceforge.net/project/showfiles.php?group_id=2055 (gp425win32.zip)
- Extract and put it somewhere
- Add directory containing `pgnuplot.exe` to path: My Computer => Properties => Advanced => Environment Variables

Install dependencies of our perl modules. Depending on how familiar you are with the perl infrastructure, the easiest might be to use PPM, the Perl Package Manager included with ActivePerl.

Install Lab::VISA

- Unzip/copy sources
- In file `Makefile.PL` adapt the LIBS and INC settings according to your installation (the location looked up above). This is what worked for me:

```
'LIBS' => ['-"IC:\\Programme\\IVI␣Foundation\\VISA\\WinNT\\
    lib\\msc\\visa32.lib"']
'INC'  => '"-IC:\\Programme\\IVI␣Foundation\\VISA\\WinNT\\
    include"'
```

  You can find the LIBS folder by checking the registry key "InstDir" in folder "HKEY_LOCAL_MACHINE\SOFTWARE\National Instruments\NI-VISA for Windows 95/NT".
- Run the following commands in the source directory

```
perl Makefile.PL
nmake
nmake install
```

Have fun!

Installation on Windows XP with Strawberry Perl

Strawberry Perl is a Perl distribution for Windows that most closely mimics a Perl installation under Linux. It comes with gcc compiler, dmake and the other relevant tools included.

Lab::VISA should in principle install out of the box with just the command

```
cpan Lab::VISA
```

executed on the commandline. Unfortunately there is a bug in ExtUtils::MakeMaker (see here) that prevents this. Two possible workarounds are explained below.

Have Windows and Strawberry Perl installed

Install NI-VISA

Download 361mb file `visa462full.exe` from NI's website

Install only 'Run Time Support' (I chose all items below that; it's not much)

Locate msc version of `visa32.lib` and `visa.h` and adjust `Makefile.PL`. This is what worked for me:

```
'LIBS' => q("-IC:/Programme/IVI␣Foundation/VISA/WinNT/lib/msc/
    visa32.lib"),
'INC'  => q("-IC:/Programme/IVI␣Foundation/VISA/WinNT/include")
    ,
```

Work around the bug (known to be present in ExtUtils-MakerMaker-6.56)

Option 1: Patch ExtUtils::MakeMaker

Apply the change described at https://rt.cpan.org/Ticket/Display.html?id=49026 to the file `Kid.pm` of your installation of ExtUtils::MakeMaker

```
perl Makefile.PL
```

Option 2: Edit generated Makefile

If you don't like to modify the installed version of ExtUtils::MakeMaker, you can edit the generated Makefile. These changes will be lost after executing `perl Makefile.PL` again though. This option is recommended if you just want to install Lab::VISA.

```
perl Makefile.PL
```

In the generated file `Makefile`:

Find the two lines containing the words `EXTRALIBS` and `LDLOADLIBS`. Add the `"C:\path\to\visa32.lib"` to each of of these lines. On my system they read:

```
EXTRALIBS = "C:\Programme\IVI␣Foundation\VISA\WinNT\lib\
    msc\visa32.lib" C:\strawberry\c\lib\libmoldname.a ...
LDLOADLIBS = "C:\Programme\IVI␣Foundation\VISA\WinNT\lib\
    msc\visa32.lib" C:\strawberry\c\lib\libmoldname.a ...
```

```
dmake
```

```
dmake install
```

Installation on Linux

As a Linux user you will probably be able to figure out things yourself. Here is a rough outline:

Before you start, you must have the VISA library by National Instrument installed. If you plan to use GPIB connections (which is very likely), you must also have the necessary drivers (NI-488.2) for your GPIB adapter card installed. Refer to National Instruments' very good documentation for additional information:

http://digital.ni.com/softlib.nsf/webcategories/85256410006C055586256BBB002C0E91?opendocu

In file `Makefile.PL` adapt the LIBS and INC settings according to your installation. This is what worked for me:

```
'LIBS'          => ['-lvisa'],
'INC'           => '-I/usr/local/vxipnp/linux/include/',
```

Then do the usual

```
perl Makefile.PL
make
make install
```

Testing the installation

Here is a quick test program that you can run with perl -Mblib test.pl:

```
#!/usr/bin/perl

use Lab::VISA;

my ($status, $sesn) = Lab::VISA::viOpenDefaultRM();

printf "status: %x (%s)\n", $status, (($status == $Lab::VISA::
    VI_SUCCESS) ? "success" : "no success");
print "sesn: $sesn\n";

my ($status, $findList, $retcnt, $instrDesc) = Lab::VISA::viFindRsrc
    ($sesn, "ASRL1::INSTR");

printf "status: %x (%s)\n", $status, (($status == $Lab::VISA::
    VI_SUCCESS) ? "success" : "no success");
print "findList: $findList\n";
print "retcnt: $retcnt\n";
print "instrDesc: $instrDesc\n";

__END__
```

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2.2 Lab::VISA

Perl interface to the National Instruments VISA library

SYNOPSIS

```
use Lab::VISA;
```

DESCRIPTION

This library offers a Perl interface to National Instruments' NI-VISA library.

With this library you can easily control the instruments in your lab (multimeters, voltage sources, magnet sources, pulse generators etc.) with Perl. You can perform complicated measurement jobs with just some Perl loops.

Lab::VISA provides a low-level interace; it is one of the possible backends for the high-level measurement control package Lab::Measurement [1].

This document describes the perl syntax of the API. Each function is explained with some sentences cited from [2]. See this manual for further documentation on the library.

Installation instructions can be found in *Lab::VISA::Installation*.

A general tutorial for using Lab::VISA and assorted packages is located in *Lab::VISA::Tutorial*.

[1] http://www.labmeasurement.de/

[2] NI-VISA Programmer Reference Manual. Part Number 370132C-01.

FUNCTIONS

viClear

```
$status=Lab::VISA::viClear($vi);
```

The `viClear()` operation performs an IEEE 488.1-style clear of the device.

viClose

```
$status=Lab::VISA::viClose($object);
```

The `viClose()` operation closes a session, event, or a find list. In this process all the data structures that had been allocated for the specified vi are freed. Calling `viClose()` on a VISA Resource Manager session will also close all I/O sessions associated with that resource manager session.

viFindNext

```
($status, $instrDesc)=
    Lab::VISA::viFindNext($findList);
```

The `viFindNext()` operation returns the next device found in the list created by `viFindRsrc()`. The list is referenced by the handle that was returned by `viFindRsrc()`.

viFindRsrc

```
($status, $findList, $retcnt, $instrDesc)=
    Lab::VISA::viFindRsrc($sesn, $expr);
```

The `viFindRsrc()` operation matches the value specified in the `expr` parameter with the resources available for a particular interface.

On successful completion, this function returns the first resource found (`instrDesc`) and returns a count (`retcnt`) to indicate if there were more resources found for the designated interface. This function also returns, in the `findList` parameter, a handle to a find list. This handle points to the list of resources and it must be used as an input to `viFindNext()`. When this handle is no longer needed, it should be passed to `viClose()`.

The search criteria specified in the `expr` parameter has two parts: a regular expression over a resource string and an optional logical expression over attribute values. The regular expression is matched against the resource strings of resources known to the VISA Resource Manager. If the resource string matches the regular expression, the attribute values of the resource are then matched against the expression over attribute values. If the match is successful, the resource has met the search criteria and gets added to the list of resources found.

All resource strings returned by `viFindRsrc()` will always be recognized by `viOpen()`. However, `viFindRsrc()` will not necessarily return all strings that you can pass to `viParseRsrc()` or `viOpen()`. This is especially true for network and `TCPIP` resources.

viGetAttribute

```
($status, $attrState)=
    Lab::VISA::viGetAttribute($object, $attribute);
```

The `viGetAttribute()` operation is used to retrieve the state of an attribute for the specified session, event, or find list.

viOpen

```
($status, $vi)=
    Lab::VISA::viOpen($sesn, $rsrcName, $accessMode, $openTimeout);
```

The `viOpen()` operation opens a session to the specified resource. It returns a session identifier that can be used to call any other operations of that resource. The address string passed to `viOpen()` must uniquely identify a resource.

For the parameter accessMode, the value `VI_EXCLUSIVE_LOCK` (1) is used to acquire an exclusive lock immediately upon opening a session; if a lock cannot be acquired, the session is closed and an error is returned. The value `VI_LOAD_CONFIG` (4) is used to configure attributes to values specified by some external configuration utility. Multiple access modes can be used simultaneously by specifying a bit-wise OR of the values other than `VI_NULL`. NI-VISA currently supports `VI_LOAD_CONFIG` only on Serial INSTR sessions.

viOpenDefaultRM

```
($status, $sesn)=
    Lab::VISA::viOpenDefaultRM();
```

The `viOpenDefaultRM()` function must be called before any VISA operations can be invoked. The first call to this function initializes the VISA system, including the Default Resource Manager resource, and also returns a session to that resource. Subsequent calls to this function return unique sessions to the same Default Resource Manager resource.

When a Resource Manager session is passed to `viClose()`, not only is that session closed, but also all find lists and device sessions (which that Resource Manager session was used to create) are closed.

viRead

```
($status, $buf, $retCount)=
    Lab::VISA::viRead($vi, $count);
```

The `viRead()` operation synchronously transfers data. The data read is to be stored in the buffer represented by buf. This operation returns only when the transfer terminates. Only one synchronous read operation can occur at any one time.

viSetAttribute

```
$status=Lab::VISA::viSetAttribute($vi, $attribute, $attrState);
```

The `viSetAttribute()` operation is used to modify the state of an attribute for the specified object.

viWrite

```
($status, $retCount)=
    Lab::VISA::viWrite($vi, $buf, $count);
```

The `viWrite()` operation synchronously transfers data. The data to be written is in the buffer represented by buf. This operation returns only when the transfer terminates. Only one synchronous write operation can occur at any one time.